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R-TR-76-012

# EFFECT OF MATERIAL MASS DISTRIBUTION ON THE LIFE OF SMALL ARMS BARRELS

DARREL M. THOMSEN

APRIL 1976



## FINAL REPORT

RESEARCH DIRECTORATE

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This report covers FY75 efforts on a project entitled, "Effect of Material Mass Distribution on the Life of Small Arms Barrels." The objective of this project is to develop a semi-empirical technique for determining gun barrel wear (or erosion) as a function of barrel material properties, wall thickness (or ratio) and firing rate. The past years task involved analytical design of test specimens (barrel geometries) for firing experiments wherein regression analyses will be performed in the determination of the effect of mass distribution on barrel life. A useful design tool applicable in the optimum design

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of gun barrels was developed with the addition of a CALCOMP plot routine to an existing implicit finite difference computer solution. Examples of these plots are given as part of the results for the parametric barrel specimen design study.

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# EFFECT OF MATERIAL MASS DISTRIBUTION ON THE LIFE OF SMALL ARMS BARRELS

## INTRODUCTION

Much effort has been spent in the pursuit of meaningful gun barrel erosion analyses. Most of these efforts have dealt with specific mechanisms and consequently have comprised only fragmentary parts of the over-all erosion problem. It is commonly accepted that a more unified approach is required to accomplish comprehensive erosion research. Further, it is believed that an immediate need exists for empirical or semi-empirical techniques which predict erosion as a function of the basic parameters involved. Toward this objective, the task herein described was undertaken to define erosion in small arms gun barrels as a semi-empirical function of barrel mass, material properties and firing rate.

A report[1] published during FY74 entitled, "Small Arms Gun Barrel Thermal Experimental Correlation Studies," describes a correlation between muzzle end wall thickness and barrel life. As shown in Figure 1, rounds to failure based on firing accuracy measurements decreased from 10,000 rounds to 2,000 rounds as barrel wall thickness decreased from .461 inches to .125 inches. These efforts are a continuation of this work toward the stated objective of better quantifying the over-all erosion process.

## ANALYTICAL APPROACH

Print-outs of the two computer programs utilized in this effort are contained in the appendixes. The first program (Appendix 1) calculates effective bore boundary conditions (propellant gas convection coefficients and temperatures) based on experimentally measured barrel temperatures. This solution utilizes an energy balance wherein the gun barrel performs as a mass type calorimeter. A complete

[1]Report No. R-TR-74-034

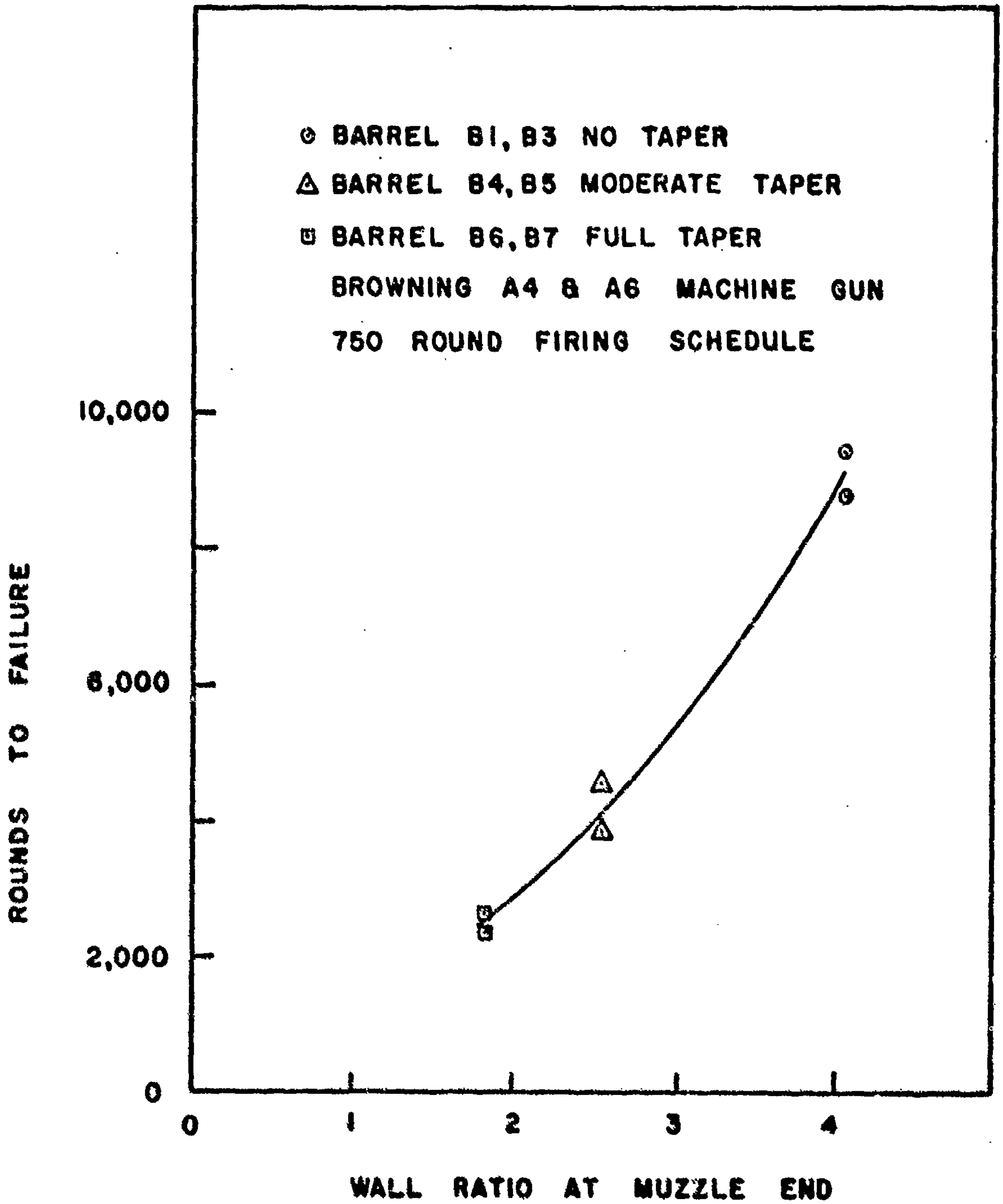


Figure 1 Geometry Effect on Barrel Life

description of this program is given in a report[1] entitled, "A Theoretical and Experimental Thermal Analysis To Determine Wall Ratios For A 30mm Tactical Barrel."

The second computer program (see Appendix 2) calculates transient gun barrel temperatures as a function of firing schedule and environmental conditions. This solution uses bore boundary conditions determined in the first program. The computer program employs an implicit finite-difference algorithm and continually performs an error analysis based on a numerical integrated energy balance. A major contribution to this effort was achieved by the incorporation of a plot routine capability. Computer graphics options which are available include:

1. Bore temperature versus firing time.
2. External barrel-temperature versus firing time.
3. Average radial temperature versus firing time.
4. Radial temperature distribution at prescribed times.

The main criteria used in selection of a test gun included; gun and ammo availability, ease of operation, and mechanism reliability. Based on these criteria, the Browning A4 was selected as a test vehicle. The over-all objective was to design axial barrel wall ratios such that the barrel would be subjected to uniform temperatures along the length of the barrel. A "gating" criterion was that of combined thermal pressure stresses. That is, the minimum thickness at any barrel section was designed of sufficient structural integrity to contain the propellant gas pressures. Consequently, subsequent to the heat transfer study, coupled thermal and pressure analyses were performed as the final design step. Once the minimum wall thickness barrel was designed, two larger barrels were designed where the wall thicknesses were arbitrarily increased in steps of .0625 inch. That is, the largest barrel has an outer diameter .250 inch larger at all axial locations than the minimum thickness barrel.

[1]Report No. R-TR-75-023

The overall procedure applied in the design of the test barrels included the following steps:

1. Experimentally firing representative gun barrels to determine bore boundary conditions.

2. Calculating effective propellant gas temperatures and convection coefficients.

3. Parametric analyses wherein barrel temperatures were calculated for a fixed rate of fire and varying wall thicknesses.

4. Combined thermal pressure stress analyses to determine the minimum allowable barrel thickness as a function of the previously determined temperatures.

## RESULTS

Results of the thermal analysis are given in Appendix 3. As previously stated the objective of this parametric study was to design gun barrels of various wall ratios to determine the effect of barrel mass on erosion. The design firing schedule was fixed at continuous burst of 400 rounds total at a firing rate of 600 rounds per minute. Results are presented at axial locations 5, 9, 15 and 21 inches from the breech end. The notes for each curve give effective convection coefficients and gas temperatures. A summary of the various wall thicknesses considered is shown in Table 1.

Shown in Table 2 is a summary of the results including calculated maximum bore pressure stresses and average barrel operating temperatures for the various outer radii. Also given is the dynamic yield strength temperature corresponding to the maximum calculated pressure stresses. The final criterion used in the design of the minimum wall ratio barrels was a maximum barrel operating temperature of 1400°F average. This criterion satisfies the yield strength requirement at all locations and is conservative at the 15 and 21 inch locations. A sketch showing the outer profiles of the minimum wall ratio test barrel is given in Figure 30 (Appendix 3). It is recommended that the two larger barrels be constructed with increasing wall thicknesses of 1/16 inch and 1/8 inch respectively at each axial location.

TABLE 1

Various Outer Radii Analyzed

| Axial Location (Inches) & Figure Number (Appendix 3) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Inches | | Fig. | Inches | Fig. | Inches | Fig. | Inches | Fig. |
| 5 | Unlined | 2 | 9 | 10 | 15 | 18 | 21 | 22 |
| | | 3 | | 11 | | 19 | | 23 |
| | | 4 | | 12 | | 20 | | 24 |
| | | 5 | | 13 | 15 | 21 | | 25 |
| | Lined | 6 | | 14 | | | | 26 |
| | | 7 | | 15 | | | | 27 |
| | | 8 | | 16 | | | | 28 |
| 5 | | 9 | 9 | 17 | | | 21 | 29 |

TABLE 2

Summary of Analytical Results
(See Appendix 3)

| Axial Location From Breech End Inches | Outer Radius Inch | Max. Yield Stress PSI | Average Barrel Operating Temperature °F | Limiting Temperature °F Based on Dynamic Yield Strength of Cr-Mo-V Steel |
|---|---|---|---|---|
| 5.0 | .674 | 92,251 | 1222 | 1240 |
| 5.0 | .612 | 93,545 | 1361 | 1400 (Data Pt.)<br>1230 (Curve) |
| 5.0 | .542 | 95,194 | 1516 | 1400 (Data Pt.)<br>1220 (Curve) |
| 9.0 | .450 | 71,133 | 1352 | 1420 |
| 9.0 | .420 | 72,453 | 1438 | 1410 |
| 15.0 | .450 | 45,673 | 1287 | 1600* |
| 15.0 | .420 | 46,521 | 1351 | 1600* |
| 15.0 | .400 | 47,218 | 1390 | 1600 |
| 15.0 | .37 | 48,537 | 1438 | 1600* |
| 15.0 | .34 | 50,332 | 1473 | 1560 |
| 21.0 | .40 | 31,350 | 1319 | 1600* |
| 21.0 | .34 | 33,418 | 1434 | 1600* |
| 21.0 | .31 | 35,111 | 1470 | 1600* |
| 21.0 | .28 | 37,666 | 1492 | 1600* |
| 21.0 | .25 | 41,874 | 1503 | 1600* |
| 21.0 | .22 | 49,680 | 1511 | 1570 |
| 21.0 | .20 | 60,678 | 1516 | 1510 |

*Extrapolated

APPENDIX 1

```
//MP3CARTC JOB (2T03,M151,7,6,9999),'D. THOMSEN',CLASS=K                     JOB 272
// EXEC FORTGCLG,REGION=100K
XXDEFAULTS PROC SYSOUT=A                                                     00000100
XXFORT     EXEC PGM=IEYFORT,REGION=100K,DPRTY=(3,3)                          00000200
XXSYSPRINT DD   SYSOUT=&SYSOUT                                               00000300
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIN   DD   DSN=&&OBJECT,UNIT=DISK,SPACE=(CYL,(1,1)),                    C00000400
XX              DCB=BLKSIZE=800,DISP=(,PASS)                                 00000500
//FORT.SYSIN DD *
IEF236I ALLOC. FOR MP3CARTC FORT
IEF237I 0C0   ALLOCATED TO SYSPRINT
IEF237I 155   ALLOCATED TO SYSLIN
IEF237I C91   ALLOCATED TO SYSIN
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS75154.T073908.RV000.MP3CARTC.OBJECT        PASSED
IEF285I   VOL SER NOS= DFSE#4.
IEF373I STEP /FORT    / START 75154.0739
IEF374I STEP /FORT    / STOP  75154.0739 CPU    0MIN 01.02SEC MAIN  94K LCS    0K

*STEP FORT    **JOB MP3CARTC*****************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)      IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       100         3        0         0             27      32         0     00:00:01.02  00:00:04.72  *
*****************************************************************************************************

XXLKED     EXEC PGM=FT1AUHAA,PARM='LIST,LET,XREF,SCTR',REGION=100K,          00000600
XX              COND=(4,LT,FORT),DPRTY=(3,3)                                 00000700
XXSYSPRINT DD   SYSOUT=&SYSOUT                                               00000800
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIB   DD   DSN=NONO.FORTLIB,DISP=SHR                                    00000900
XXSYSLIN   DD   DSN=&&OBJECT,DISP=(OLD,DELETE)                               00001000
XX         DD   DDNAME=SYSIN                                                 00001100
XXSYSUT1   DD   UNIT=DISK,SPACE=(CYL,(1,1))                                  00001200
XXSYSLMOD  DD   DSN=&&LOAD(MAIN),UNIT=DISK,SPACE=(CYL,(1,5,1)),              C00001300
XX              DISP=(,PASS)                                                 00001400
IEF236I ALLOC. FOR MP3CARTC LKED
IEF237I 0C0   ALLOCATED TO SYSPRINT
IEF237I 150   ALLOCATED TO SYSLIB
IEF237I 155   ALLOCATED TO SYSLIN
IEF237I 155   ALLOCATED TO SYSUT1
IEF237I 145   ALLOCATED TO SYSLMOD
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS1.FORTLIB                                  KEPT
IEF285I   VOL SER NOS= DFSELB.
IEF285I   SYS75154.T073908.RV000.MP3CARTC.OBJECT        DELETED
IEF285I   VOL SER NOS= DFSE#4.
IEF285I   SYS75154.T073908.RV000.MP3CARTC.R0000004      DELETED
IEF285I   VOL SER NOS= DFSE#4.
IEF285I   SYS75154.T073908.RV000.MP3CARTC.LOAD          PASSED
IEF285I   VOL SER NOS= DFSE#3.
IEF373I STEP /LKED    / START 75154.0739
IEF374I STEP /LKED    / STOP  75154.0740 CPU    0MIN 01.04SEC MAIN  95K LCS    0K

*STEP LKED    **JOB MP3CARTC*****************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)      IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       100       162        0         0              0      74         0     00:00:01.04  00:00:37.23  *
*****************************************************************************************************

XXGO       EXEC PGM=*.LKED.SYSLMOD,COND=((4,LT,FORT),(4,LT,LKED)),           C00001500
XX              DPRTY=(3,3)                                                  00001600
XXFT05F001 DD   DDNAME=SYSIN                                                 00001700
```

```
XXFT06F001 DD   SYSOUT=&SYSOUT                                                        00001800
IEF653I SUBSTITUTION JCL - SYSOUT=A                                                   00001900
XXFT07F001 DD   SYSOUT=B
//GO.SYSIN DD *
//
IEF236I ALLOC. FOR MP3CARTC GO
IEF237I 145   ALLOCATED TO PGM=*.DD
IEF237I 093   ALLOCATED TO FT05F001
IEF237I 0C0   ALLOCATED TO FT06F001
IEF237I 140   ALLOCATED TO FT07F001
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS75154.T073635.RV000.MP3CARTC.LOAD          PASSED
IEF285I   VOL SER NOS= FSE#3.
IEF373I STEP /GO      / START 75154.0740
IEF374I STEP /GO      / STOP  75154.0740 CPU    0MIN 00.20SEC MAIN  20K LCS    0K

*STEP GO       C-JOB MP3CARTC*********************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)      IN-HASP(IO)-OUT OTHER(IO)   CP   TME(C) STEP TIME(T) *
*USAGE-       130       6         0          0            3         7         0   00.   0.20  0:00:02.4  *
**************************************************************************************************

IEF285I   SYS75154.T073906.RV000.MP3CARTC.LOAD          DELETED
IEF285I   VOL SER NOS= FSE#3.
IEF375I  JOB /MP3CARTC/ START 75154.0734
IEF376I  JOB /MP3CARTC/ STOP  75154.0740 CPU    0MIN 02.26SEC

*JOB MP3CARTC**2TG3***BISHOP, THOMSEN*************************************************************
*UNITS- CORE(K*T)   DISK(IO)   TAPE(IO)  TAPE(U*T)  HASPI(IO)  HASPO(IO)  OTHER(IO)    CPU(C)     TOTAL  *
*COSTS-     $0.01      $0.05      $0.00      $0.00      $0.00      $0.00      $0.00     $0.14     $0.20  *
**************************************************************************************************
```

9

```
      IMPLICIT REAL*8(A-Z)
      READ 1,RHO,TA,T1,T2,DTDT1,DTDT2,HO1,HO2,H1,RO,R1,CP,DT2
      PRINT 1,RHO,TA,T1,T2,DTDT1,DTDT2,HO1,HO2,H1,RO,R1,CP,DT2
    1 FORMAT(8F10.5/6F10.5)
      CC=RHO*CP*(RO**2-R1**2)
      KA1=CC*DTDT1*3600.
      KA2=CC*DTDT2*3600.
      KB1=HO1*2.*RO*(T1-TA)
      KB2=HO2*2.*RO*(T2-TA)
      K1=(KA1+KB1)/(2.*R1)
      K2=(KA2+KB2)/(2.*R1)
      A=DTDT1/DTDT2
      C3=T2-T1
      MG=(K1-K2)/(C3*DT2*(1.-A))
      TG = 1./MG*((KA2 + KB2)/(2.*R1)) + T2 + DT2
      BDYH=15.0/MG
      PRINT 2,MG,TG,BDYH
      PRINT 3,KA1,KA2
      PRINT 3,KB1,KB2
      PRINT 3,K1,K2
      PRINT 3,C3
    3 FORMAT(10X,3F20.10)
    2 FORMAT(10X,'MG=',F10.5,10X,'TG=',F10.5,10X,'BDYH=',F10.5)
      CALL EXIT
      END
```

```
490.00000  45.00000 225.00000[illegible]50.00000  30.00000   6.50000   1.00000   5.00000
  0.00758   0.02446   0.11000 150.00000
       MG= 726.85640            TG=1266.49174          [illegible]    1.02064
            3190.9742422483         [illegible].1958524480
               6.80563.0000        245.6230[illegible]
          225973.507220[illegible]      62430.7099146441
              625.00000[illegible]
```

APPENDIX 2

```
//MKOL4R01 JOB (2T03,M140,5,4,9999),'D. THOMSEN: PLOT'                        JOB 897
// EXEC SIMPLOTF,PLOTTER=PLOTTER,MAXPLTS=24,PARM.PLOT='D. THOMSEN',
// REGION=150K
XXSIMPLOTF PROC SYSOUT=A,MAXPLTS=10,PLOTTER=PRINTER                         00000010
XXFORT     EXEC PGM=IEYFORT,REGION=100K,DPRTY=(3,3)                          00000020
XXSYSPRINT DD   SYSOUT=&SYSOUT                                               00000030
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIN   DD   DSN=&&OBJECT,UNIT=DISK,SPACE=(CYL,(1,1)),                   C00000040
XX              DCB=BLKSIZE=400,DISP=(,PASS)                                 00000050
//FORT.SYSIN DD *
IEF236I ALLOC. FOR MKOL4B01 FORT
IEF237I 000   ALLOCATED TO SYSPRINT
IEF237I 145   ALLOCATED TO SYSLIN
IEF237I 090   ALLOCATED TO SYSIN
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS75094.T113535.RV000.MKOL4B01.OBJECT        PASSED
IEF285I   VOL SER NOS= DFSEW3.
IEF373I STEP /FORT    / START 75094.1135
IEF374I STEP /FORT    / STOP  75094.1137 CPU    0MIN 19.34SEC MAIN 100K LCS    0K

*STEP FORT     **JOB MKOL4B01*******************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)      IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       150       44        0         0          556       617        0     00:00:19.34  00:01:10.43  *
*************************************************************************************************

XXLKED     EXEC PGM=FT1AOM4A,PARM='LIST,LET,NOXREF,SCTR',REGION=98K,        C00000060
XX              COND=(4,LT,FORT),DPRTY=(3,3)                                 00000070
XXSYSPRINT DD   SYSOUT=&SYSOUT                                               00000080
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXSYSLIB   DD   DSN=SYS1.FORTLIB,DISP=SHR                                    00000090
XX         DD   DSN=MPATSCH.SIMPLOT.FORTLIB,DISP=SHR                         00000100
XXSYSLIN   DD   DSN=&&OBJECT,DISP=(OLD,DELETE)                               00000110
XX         DD   DDNAME=SYSIN                                                 00000120
XXSYSUT1   DD   UNIT=DISK,SPACE=(CYL,(1,1))                                  00000130
XXSYSLMOD  DD   DSN=&&LOAD(MAIN),UNIT=DISK,SPACE=(CYL,(1,5,1)),             C00000140
XX              DISP=(,PASS)                                                 00000150
IEF236I ALLOC. FOR MKOL4B01 LKED
IEF237I 000   ALLOCATED TO SYSPRINT
IEF237I 150   ALLOCATED TO SYSLIB
IEF237I 265   ALLOCATED TO
IEF237I 145   ALLOCATED TO SYSLIN
IEF237I 145   ALLOCATED TO SYSUT1
IEF237I 145   ALLOCATED TO SYSLMOD
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   SYS1.FORTLIB                                  KEPT
IEF285I   VOL SER NOS= DFSEL8.
IEF285I   MPATSCH.SIMPLOT.FORTLIB                       KEPT
IEF285I   VOL SER NOS= DMSE01.
IEF285I   SYS75094.T113535.RV000.MKOL4B01.OBJECT        DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF285I   SYS75094.T113535.RV000.MKOL4B01.R0000004      DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF285I   SYS75094.T113535.RV000.MKOL4B01.LOAD          PASSED
IEF285I   VOL SER NOS= DFSEW3.
IEF373I STEP /LKED    / START 75094.1137
IEF374I STEP /LKED    / STOP  75094.1138 CPU    0MIN 01.79SEC MAIN  98K LCS    0K

*STEP LKED     **JOB MKOL4B01*******************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)      IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       150      356        0         0            0         5        0     00:00:01.79  00:01:01.63  *
```

```
**************************************************************************************************************
XXGO       EXEC PGM=* LKED.SYSLMOD,COND=((4,LT,FORT),(4,LT,LKED)),       C00000160
XX              DC  (=,1,3)                                                00000170
XXGO.FT14F001 DD    & EM&SM,UNIT=SYSDA,DISP=(NEW,PASS),                    00000180
XX SPACE=(800,(120,15)),DCB=(RECFM=VS,LRECL=796,BLKSIZE=800)               00000190
XXFT05F001 DD   DDNAME=SYSI.                                               00000200
XXFT06F001 DD   SYSOUT=&SYSOUT                                             00000210
IEF653I SUBSTITUTION JCL - SYSOUT=A
XXFT07F001 DD   SYSOUT=A                                                   00000215
//GO.SYSIN DD *
IEF236I ALLOC. FOR MKOL4801 GO
IEF237I 145   ALLOCATED TO PGM=*.DD
IEF237I 145   ALLOCATED TO FT14F001
IEF237I 091   ALLOCATED TO FT05F001
IEF237I 00C   ALLOCATED TO FT06F001
IEF237I 1A0   ALLOCATED TO FT07F001
IEF142I - STEP WAS EXECUTED - COND CODE 0016
IEF285I   SYS75094.T113535.RV000.MKOL4801.LOAD          PASSED
IEF285I   VOL SER NOS= DFSE=3.
IEF285I   SYS75094.T113535.RV000.MKOL4801.SM            PASSED
IEF285I   VOL SER NOS= DFSE=3.
IEF373I STEP /GO      / START 75094.1136
IEF374I STEP /GO      / STOP  75094.1140 CPU   1MIN 08.34SEC MAIN  96K LCS   0K

*STEP GO      **JOB MKOL4801**************************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       150        49        0         0          61     3026          0    00:01:08.34  00:02:28.85  *
**************************************************************************************************************

XXPLOT FXEC PGM=&PLOTTER,REGION=104K,                                      00000220
IEF653I SUBSTITUTION JCL - PGM=PLOTTER,REGION=104K,
XX  COND=((4,LT,FORT),(4,LT,LKED),(16,LT,GO))                              00000230
XXSTEPLIB DD DSN=MPATSCH.SIMPLOT.PROG,DISP=SHR                             00000240
XXFT03F001 DD SYSOUT=&,SPACE=(14588,(6MAXPLTS)),                           00000250
IEF653I SUBSTITUTION JCL - SYSOUT=A,SPACE=(14588,(24)),
XX DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1862,HIARCHY=1)                        00000260
XXFT05F001 DD SYSOUT=A,DCB=HIARCHY=1                                       00000270
XXFT14F001 DD DSNAME=&SM,DISP=(OLD,PASS),DCB=HIARCHY=1                     00000280
XXFT15F001 DD SYSOUT=(M,,+4),DCB=(RECFM=VBS,LRECL=76,BLKSIZE=80)           00000290
//
IEF236I ALLOC. FOR MKOL4801 PLOT
IEF237I 265   ALLOCATED TO STEPLIB
IEF237I 0C1   ALLOCATED TO FT03F001
IEF237I 000   ALLOCATED TO FT06F001
IEF237I 145   ALLOCATED TO FT14F001
IEF237I 1F0   ALLOCATED TO FT15F001
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF285I   MPATSCH.SIMPLOT.PROG                           KEPT
IEF285I   VOL SER NOS= UMSE01.
IEF285I   SYS75094.T113535.RV000.MKOL4801.SM             PASSED
IEF285I   VOL SER NOS= DFSE=3.
IEF373I STEP /PLOT    / START 75094.1140
IEF374I STEP /PLOT    / STOP  75094.1141 CPU   0MIN 05.19SEC MAIN  92K LCS   0K

*STEP PLOT    **JOB MKOL4801**************************************************************************
*RESOURCE- CORE(K)  DISK(IO)  TAPE(IO)--UNITS(U)     IN-HASP(IO)-OUT OTHER(IO)    CPU TIME(C) STEP TIME(T)  *
*USAGE-       150       110        0         0           0      448          0    00:00:05.19  00:00:29.77  *
**************************************************************************************************************
```

```
IEF285I   SYS75094.T113535.RV000.MKOLAB01.LOAD          DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF285I   SYS75094.T113535.RV000.MKOLAB01.SM            DELETED
IEF285I   VOL SER NOS= DFSEW3.
IEF375I  JOB /MKOLAB01/ START 75094.1135
IEF376I  JOB /MKOLAB01/ STOP  75094.1141 CPU   1MIN 34.66SEC

*JOB MKOLAB01**2T03***16J**'.  THOMSEN PLOT************************************************************
*UNITS- CORE(K*T)   DISK(IO)   TAPE(IO)  TAPE(U*T)  MASPI(IO)  MASPO(IO)  OTHER(IO)     CPU(C)      TOTAL  *
*COSTS-     $0.85      $0.17      $0.00      $0.00      $0.00      $0.00      $0.00      $5.78      $6.80  *
*********************************************************************************************************
```

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 75094          11/35/51                PAGE 0001

              C  ONE-DIMENSIONAL TRANSIENT HEAT CONDUCTION PROGRAM (HT-2A)
              C  PROGRAMMED BY A.M.CLAUSING.  VERSION = 1 JULY 1970
              C  THIS PROGRAM IS A GENERAL PROGRAM FOR THE SOLUTION OF CONDUCTION
              C  PROBLEMS WITH TEN OR LESS REGIONS INCLUDING INTERFACIAL RESISTANCES
              C  BETWEEN REGIONS
 0001               DIMENSION ANS(99).NPLOT(11).TT(150).RHOP(100).CPP(100).TTT(150)
              C
              C**DEFINITION OF LABELED COMMON -- BLK1.BLK2. AND BLK3
 0002               COMMON /BLK1/ T(150).C(150).C4(150).H(150).HX(150).IBODY(10.2)
 0003               COMMON /BLK2/ RADII(11).NODES(10).XKZ(150).BETA(10).CP(10).
                   2RHO(10).EMISS.RHOZ.CPZ.XKRZ.RDYR(11).RI(150).RII(150).UR(10).
                   2A(9).ITR(11)
 0004               COMMON /BLK3/ YY(500.10).TAU(500).Q(500).ISYM.XMIN.XMAX.YMIN.YMAX.
                   2IPLOT(11). TIM(150).TTP(150) . TTO(150).TS(150)
 0005               COMMON /BLK4/ KOUNT.J1.J2.J3.J4.NSUP
              C
              C**INITIALIZATION OF VARIABLES NOT LOCATED IN LABELED COMMON
 0006               DATA ANS.NPLOT.TNUM.TDENOM.DZ.DTIMEX.DDTX.IX.NBODY/.2..4.1.0.2.0.
                   295*.0. 11*0. .0. 1.. 1.. .0005..25. 3. 2/
              C
              C**READ CHARACTERISTICS OF PROBLEM -- RAW INPUT DATA
              C
              C**DEFINITION OF NAM AND NAM1
 0007               NAMELIST /NAM/ T.ANS.ISYM.YMAX.YMIN.XMAX.XMIN.NPLOT.TNUM.TDENOM.
                   2NODES.XKZ.BETA.CP.RHO.RDYR.EMISS.DZ.   DTIMEX.DDTX.IX.NBODY.CPZ.
                   3RHOZ.XKRZ.RADII.A.ITB.NSUP
                   4/NAM1/DTIMEX.DDTX.DZ.II.NBODY.IX.XKRZ.RHOZ.CPZ.EMISS.TNUM.TDENOM.
                   5ISYM.XMAX.XMIN.YMAX.YMIN.NPLOT.NODES.ANS.A.ITB.IPLOT
 0008               DIMENSION TIMEF(250).F(250)
 0009               READ 100.N
 0010         100   FORMAT(I5)
 0011               READ 200. (TIMEF(I).F(I).I=1.N)
 0012         200   FORMAT (8F10.5)
 0013               PRINT 202
 0014         202   FORMAT (8X.'TIMEF'.25X.'F')
 0015               PRINT 203. (TIMEF(I).F(I).I=1.N)
 0016         203   FORMAT (5X.F10.5.16X.F10.5)
 0017               KOUNT=1
 0018               J1=1
 0019               J2=1
 0020               J3=1
 0021               J4=1
 0022         25    READ(5.NAM)
              C
              C**CALCULATE DIMENSIONLESS LUMPED PARAMETERS. HX(I) AND C(I)
 0023               CALL LUMP (II.NBODY.DZ)
              C
              C**WRITE PROBLEM PARAMETERS
 0024               WRITE(6.3)
 0025         3     FORMAT(29H1HEAT TRANSFER PROGRAM HT-2A /27H PROGRAMMED BY A.M.CLAU
                   2SING/30H CRANK-NICOLSON ALGORITHM
                   3    /26H VERSION = 1 JULY 1970     ///25H THE INPUT PARAMETERS ARE)
 0026               WRITE(6.NAM1)
```

```
 0027          WRITE(6,5)                                                       00370
 0028     5    FORMAT(7HOSEGLIN,3X5HIBODY,3X 9HRADII(FT),5X6HDR(FT),5X8HBDYR(FT),  00380
              26X2HCP,8X3HRHO,6X2HK2,6X4HBETA )                                   00390
 0029          WRITE(6,7) (J,IBODY(J,1),IBODY(J,2),RADII(J),DR(J),BDYR(J),CP(J),  00400
              2RHO(J),XK2(J), BETA(J), J=1,NBODY)                                 00410
 0030     7    FORMAT(I3,I5,I4,3E12.3,  F10.3,2F10.1,F11.6)                       00420
 0031          I = NBODY + 1                                                      00430
 0032          WRITE(6, 9)I,RADII(I),ROTR(I)                                      00440
 0033     9    FORMAT(I3,12X,E12.3,12X,E12.3//)                                   00450
 0034          WRITE(6,11)                                                        00460
 0035    11    FORMAT(3X1HI,7X5H M(I), 12X4HC(I), 12X4HT(I),  7X6HRADIUS )         00470
 0036          WRITE(6,13)(I, M(I),C(I),T(I),RI(I),   I=1,II)                      00480
 0037    13    FORMAT(I4,2E16.4,F13.2,F13.5)                                      00490
          C                                                                       00500
          C**CALCULATE OR INITIALIZE VARIOUS QUANTITIES --- SAVE T(I) AND DTIMEX  00510
 0038          TSEC = DZ**2*RHOZ*CPZ*3600./XKRZ                                   00520
 0039          IIM1 = II - 1                                                      00530
 0040          IIM2 = II - 2                                                      00540
 0041          IIP1 = II + 1                                                      00550
 0042          IF(ANS(1).GT..0) GO TO 131                                         00560
 0043          DO 133 I=1,29                                                      00570
 0044     133 ANS(I) = ANS(I)/TSEC                                                00580
 0045          ANS(1) = -ANS(1)                                                   00590
 0046     131 DO 15 I=1,IIP1                                                      00600
 0047    15    TT(I) = T(I)                                                       00610
 0048          ATIME = DTIMEX                                                     00620
 0049          ODOTX=DOTX                                                         00630
 0050          N=0                                                                00640
 0051          IANS=1                                                             00650
 0052          TAUT = .0                                                          00660
 0053          TAU(1) = .0                                                        00670
 0054          ITIM = 0
          C
 0055          SQIN=0.0
 0056          SQSTR=0.0
 0057          SQUT=0.0
 0058          NT=0
 0059          DO 17 J=1,NBODY
 0060          NT1=NT + 1
 0061          NT=NODES(J) + NT
 0062          NTM1 = NT - 1
 0063          DO 17 I=NT1,NT
 0064          CPP(I)=CP(J)
 0065      17 RHOP(I)=RHO(J)
          C                                                                       00680
          C                                                                       00820
          C**START OF SOLUTION OF PROBLEM                                         00830
          C  POINT OF MAJOR LOOP ENTRY -- SN25(NO NEW DTIMEX), SN24(NEW DTIMEX)   00840
 0066     24   DO 14 I=2,IIM1                                                     00850
 0067     14   CX(I) = C(I)/DTIMEX*2.                                             00860
 0068      25  CALL LUMP (II,NBODY,DZ)                                            00870
 0069          CALL CHANGE(NBODY,TSEC,TAUT,II,IX,N)                               00871
          C    TIME=TAUT*TSEC
```

```
            C      WA(I) = WAOT(I)/ROTP(I)
            C      CALL LINEAR(TIME,TIMEF,F,FACTOR)
            C      WA(I)=WA(I)*FACTOR                                         00880
 0070              CALL SOLVE (IIM1,IIM2,II,RHODT,BETA)
            C  ENERGY BALANCE (ONE ROD)
 0071              DETM=DTIMEX*TSEC/3600.0
 0072              QSTM=0.0
 0073              QSTM = (RI(2) - RI(1))/2.*RHOP(1)*CPP(1)*6.2832*(RI(1) +
                  1(RI(2) - RI(1))/4.)*(T(2) - TS(2))
 0074              QSTM = (RI(NT+1) - RI(NT))/2.*RHOP(NT)*CPP(NT)*6.2832*(RI(NT+1) -
                  1(RI(NT+1) - RI(NT))/4.)*(T(NT+1) - TS(NT+1)) + QSTR
 0075              DO 27 I= 2,NT-1
 0076              QSTM=(RI(I+1) - RI(I))*RHOP(I)*CPP(I)*6.2832*RI(I)*(T
                  1(I+1) - TS(I+1)) + QSTR
 0077           27 CONTINUE
 0078              QIN=HI(1)*XKRZ*6.2832*(T(1) - T(2))
 0079              QOUT = HE(IIM1)*XKRZ*6.2832*(T(IIM1) - T(II))
 0080              SQIN = SQIN + QIN*DETM
 0081              SQSTR = SQSTR + QSTR
 0082              SQOUT = SQOUT + QOUT * DETM
 0083              SUM = SQSTR + SQOUT
 0084              ENBL = (SQIN - SUM) / SQIN*100.0
            C
 0085              DO 30 I = 1,IIP1
 0086           30 TS(I) = T(I)                                               00890
 0087              N = N + 1                                                  00900
 0088              TAUT = TAUT +DTIMEX                                        00910
            C                                                                 01010
            C                                                                 01020
            C**END OF TIME STEP                                               01030
            C**IF TIMEX=DDDTX DOUBLE TIME INCREMENT                           01040
 0089           21 IF(TAUT.LT.DDDTX) GO TO 29                                 01050
 0090              IRET = 1                                                   01060
 0091              DTIMEX = DTIMEX*2.                                         01070
 0092              DDDTX = 2.*DDDTX                                           01080
 0093              WRITE(6,31) DTIMEX,TAUT                                    01090
 0094           31 FORMAT(//57H TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT 1 01100
                  2S = ,F7.4/34H THE CURRENT DIMENSIONLESS TIME IS =,F7.4)    01040
            C  21 IF(TAUT.LT.DDDTX) GO TO 29                                  01050
            C      IRET = 1                                                   01060
            C      DTIMEX = DTIMEX*2.                                         01070
            C      DDDTX = 2.*DDDTX                                           01080
            C      WRITE(6,31) DTIMEX,TAUT                                    01090
            C   31 FORMAT(//57H TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT 1 01100
            C     2S = ,F7.4/34H THE CURRENT DIMENSIONLESS TIME IS =,F7.4)
            C    INCREASE TIME INCREMENT FOR COOLING
            C      IF(FACTOR .LT. .5 ) GO TO 260
            C      IF(FACTOR .GT. .5 ) GO TO 280
            C 260 DTIMEX = .005
            C      GO TO 300
            C 280 DTIMEX = .0005
            C 300 IRET = 1
 0095              GO TO 33
```

```
0096          28  IRET = 2
              C                                                                   01130
              C***IF TAUT.GT.ANS(IANS) PRINT TEMPERATURE DISTRIBUTIONS ETC.       01140
0097          33      IF(TAUT.LT.ANS(IANS)) GO TO (24,25),IRET                     01150
0098                  IANS = IANS + 1                                              01160
0099                  CALL RESULT(TAUT,TIM1,TI,THUM,TOEXOM,DZ,HBODY,ANS,IANS,NC,NPLT, 01170
                     &NPLOT,TIMEX,TIP1,SOIN,SOSTM,SWUT,ENBL,TIM2,ITIM)             01180
0100                  IF(ANS(IANS).NE.0) GO TO (24,25),IRET                        01190
              C                                                                   01200
              C***RESET INITIAL CONDITION AND TIME INCREMENT -- READ NEXT CASE -- SN26  01210
0101          35      DTIME = DTIME                                                01220
0102                  DO 37 I=1,IIX                                                01230
0103                  TS(I) = TTT(I)                                               01239
0104          37      TI(I) = TTT(I)                                               01240
0105                  GO TO 26                                                     01250
0106                  END                                                          01260
```

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FORTRAN IV G LEVEL  21                MAIN                DATE = 76094          11/35/51             PAGE 0005

 *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =       56
 *STATISTICS*     SOURCE STATEMENTS =      106,PROGRAM SIZE =      6734
 *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE LUMP(II,NBODY,DZ)
      COMMON /BLK1/ T(150),C(150),CR(150),RI(150),RX(150),IBODY(10,2)
      COMMON /BLK2/ RADII(11),NODES(10),AKZ(150),BETA(10),CP(10),
     ZRHO(10),EM(55),RHOZ,CPZ,AKRZ,RDTR(11),RI(150),RII(150),DR(10),
     ZA(10),IRH(11)
C***THIS SUBROUTINE CALCULATES THE DIMENSIONLESS LUMPED PARAMETERS
      AZ=RHOZ*CPZ*DZ**2
      CI = .0
      C(1) = .0
      IF(RDTR(1).EQ..0) GO TO 3
      RX(1) = RADII(1)/RDTR(1)
      R(1) = RX(1)
      IBODY(1,1) = 2
      GO TO 5
3     IBODY(1,1) = 1
5     RI(1) = RADII(1)
C
C***BEGINNING OF LOOP TO CALCULATE C(I) AND R(I) FOR NBODY REGIONS(J)
      DO 9 J=1,NBODY
      DRR = RADII(J+1) - RADII(J)
      DR(J) = DRR/FLOAT(NODES(J)-1)
      IBODY(J,2) = IBODY(J,1) + NODES(J) - 1
      IB = IBODY(J,1)
      IE = IBODY(J,2) - 1
      RI(IB) = RADII(J)
C
C***CALCULATION OF C(I) AND R(I) FOR REGION J
      AJ = RHO(J)*CP(J)*DR(J)/AZ
      C(IB) = AJ*(RI(IB) + DR(J)/4.)/2.+ CI
      BJ = AKZ(J)/(AKRZ*DR(J))
      DO 1 I=IB,IE
      IF(T(I)-1672.) 10,10,14
10    AKZ(I) = 24.3-.00870*T(I)
      GO TO 20
14    AKZ(I) = 10.39+.00347*T(I)
20    R(I) = BJ*(RI(I) + DR(J)/2.)
C     R(I) = BJ*(RI(I)+DR(J)/2.)
      RI(I+1) = RI(I) + DR(J)
1     C(I+1) = AJ*RI(I+1)
      C(IE+1) = AJ*(RI(IE+1)-DR(J)/4.)/2.
C
C***CHECK TO SEE IF INTERFACIAL RESISTANCE IS ZERO AND PROCEED ACCORDINGLY
      IF(RDTR(J+1).EQ..0) GO TO 2
      CI = .0
      IBODY(J+1,1) = IBODY(J,2) + 1
      RX(IE+1)= RI(IE+1)/RDTR(J+1)
      R(IE +1) = RX(IE+1)
      GO TO 9
2     CI = C(IE+1)
      IBODY(J+1,1) = IBODY(J,2)
9     CONTINUE
      IF(RDTR(NBODY+1).NE..0) GO TO 11
      II = IE + 1
```

```
0044           GO TO 13                                                  01750
0045     11    II = IE +2                                                01760
0046           C(II) = .0                                                01770
0047     13    H(II) = .0                                                01780
0048           RI(II)= RADII(NBODY + 1)                                  01790
         C                                                               01800
         C**CALCULATE THE DIMENSIONLESS RADIUS RII                       01810
0049           DO 16 I=1,II                                              01820
0050     16    RII(I) = (RI(I) - RADII(1))/(RADII(NBODY+1) - RADII(1))   01830
0051           RETURN                                                    01840
0052           END                                                       01850
```

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FORTRAN IV G LEVEL  21                 LUMP              DATE = 75094          11/35/51              PAGE 0003

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = LUMP     , LINECNT =       55
  *STATISTICS*    SOURCE STATEMENTS =       52,PROGRAM SIZE =      1504
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  21                LINEAR              DATE = 75094          11/35/51              PAGE 0001

 0001                   SUBROUTINE LINEAR(A,X,Y,YY)
 0002                   DIMENSION X(1),Y(1)
 0003                   I=1
              C       1 IF(Y(I+1) .LT. Y(I)) GO TO 100
              C              USE FOLLOWING IF AS Y INCREASES X INCREASES
 0004              11 IF(A-X(I))3,2,2
              C              USE FOLLOWING IF AS Y INCREASES X DECREASES
              C 100 IF(A-X(I))3,2,3
 0005               2 I=I+1
 0006                 GO TO 11
 0007               3 I=I-1
 0008                 YY=Y(I)*(A-X(I+1))/(X(I)-X(I+1))+Y(I+1)*(A-X(I))/(X(I+1)-X(I))
 0009                 RETURN
 0010                 END
```

```
*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = LINEAR  , LINECNT =       55
*STATISTICS*    SOURCE STATEMENTS =       10,PROGRAM SIZE =      506
*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL  21                SOLVE              DATE = 75094          11/35/51                PAGE 0001

0001          SUBROUTINE SOLVE (IIM1,IIM2,II,NBODY,BETA)
0002          DIMENSION GE(150),FE(150),DE(150),BETA(10),BE(150), BI(150)
0003          COMMON /ALF1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)
        C
        C**CORRECT THE BODY CONDUCTANCES FOR VARIABLE CONDUCTIVITIES
0004    1     DO 3  J=1,NBODY
0005          IB = IBODY(J,1)
0006          IE= IBODY(J,2) - 1
0007          DO 3  I=IB,IE
0008    3     HX(I) = H(I)*(1. + BETA(J)*(T(I) + T(I+1))/2.)
        C
        C**START OF ELIMINATION -- CRANK-NICOLSON ALGORITHM
0009          DO 9 I=2,IIM1
0010          C1 = HX(I) + HX(I-1)
0011          BE(I) = CX(I) + C1
0012    9     BI(I) = CX(I) - C1
0013          GE(2) = BE(2)
0014          FE(2) = (BI(2)*T(2) + HX(2)*T(3) + HX(1)*T(1)*2.)/GE(2)
0015          DO 5 I=3,IIM1
0016          DE(I) = -HX(I-1)/GE(I-1)
0017          GE(I) = BE(I) + HX(I-1)*DE(I)
0018    5     FE(I) = (HX(I)*T(I+1) + HX(I-1)*T(I-1) + BI(I)*T(I) + HX(I-1)*
             2 FE(I-1))/GE(I)
0019          FE(IIM1) = FE(IIM1) + HX(IIM1)*T(II)/GE(IIM1)
        C
        C**BACK SUBSTITUTION
0020          T(IIM1) = FE(IIM1)
0021          DO 7 I=2,IIM2
0022          J = II - I
0023    7     T(J) = FE(J) - DE(J+1)*T(J+1)
0024          RETURN
0025          END
```

```
FORTRAN IV G LEVEL  21                SOLVE             DATE = 75094          11/35/51            PAGE 0002

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = SOLVE    , LINECNT =        55
  *STATISTICS*    SOURCE STATEMENTS =        25,PROGRAM SIZE =      4034
  *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL  21              RESULT              DATE = 75094          11/35/51                    PAGE 0001

 0001             SUBROUTINE RESULT(TAUT,IIM1,II,TNUM,TDENOM,DZ,NBODY,ANS,IANS,NC,        02180
                 2NPRT,NPLOT,DTIMEX,IIP1,SQIN,SQSTR,SQUT,ENBL,IIM2,ITIM)
 0002             DIMENSION TSTAR(150),XM(10),ANS(30),NPLOT(11),Y(500), TT(150)           02200
 0003             COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)          02210
 0004             COMMON /BLK2/ RADII(11),NODES(10),XKZ(150),BETA(10),CP(10),             02220
                 2RHO(10),EMISS,RHOZ,CPZ,XKRZ,RDYR(11),RI(150),RII(150),DR(10),           02230
                 2A(9),ITB(11)                                                            02231
 0005             COMMON /BLK3/ YY(500,10),TAU(500),Q(500),ISYM,XMIN,XMAX,YMIN,YMAX,      02240
                 2IPLOT(11), TIM(150),TTR(150) , TTO(150),TS(150)                         02241
 0006             COMMON /BLK4/ KOUNT,J1,J2,J3,J4,NSUP
 0007             REAL DATX(50),DATY(50)
            C                                                                             02250
            C**CALCULATE DIMENSIONAL TIME,HEAT FLOWS PER UNIT DEPTH, TSTARS, M'S          02260
            C**AND WEIGHTED AVERAGE TEMPERATURE.  PRINT THESE QUANTITIES.                 02270
 0008              CALL TAVE(II,IIP1)                                                     02280
 0009              TSEC  = DZ**2 * RHOZ* CPZ * 3600./ XKRZ                                02290
 0010             TIME = TAUT * TSEC                                                      02300
 0011             QIN = HX(1)*XKRZ*6.2832*(T(1) - T(2))                                   02310
 0012             QOUT = HX(IIM1)*XKRZ*6.2832*(T(IIM1) - T(II))                           02320
 0013             HOUT=HX(IIM1)*XKRZ/RI(IIM1)
 0014             HCON=XKRZ/RDYR(NBODY+1)
 0015             HRA=HOUT-HCON
 0016             HIN=HX(1)*XKRZ/RADII(1)
 0017             DO 1 I=1,IIP1                                                           02330
 0018       1     TSTAR(I) = (T(I) - TNUM)/TDENOM                                         02340
 0019             DO 3 J=1,NBODY                                                          02350
 0020       3     XM(J) = DR(J)**2/(DTIMEX*DZ**2)                                         02360
 0021             WRITE(6,5) TAUT                                                         02370
 0022       5     FORMAT(////22H0 DIMENSIONLESS TIME =,F7.3,10X28HHEAT FLOW PER FT (      02380
                 28TU/HR-FT),10X48HCOMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F))      02390
 0023             WRITE(6,7) TIME,QIN,QOUT,HOUT,HRA                                       02400
 0024       7     FORMAT(22H  REAL TIME (SECONDS)=,E11.3,3X4HQIN=E12.3,7H  QOUT=,E12      02410
                 2.3,3X7H HR+HC=,E12.3,3X3HHR=,E12.3)
 0025             WRITE(6,20) SQIN,SQSTR,SQUT,ENBL
 0026      20     FORMAT(/5X,'SUMQIN=',F10.5,10X,'SUMQSTR=',F10.5,10X,'SUMQOUT=',
                 2F10.5,10X,'ENERGY BALANCE=',F10.5)
 0027             WRITE(6,9) (XM(I),I=1,NBODY)                                            02430
 0028       9     FORMAT(39H0 M VALUES FOR REGIONS 1 THRU NBODY ARE,10F6.2)               02440
 0029             WRITE(6,8) HIN
 0030       8     FORMAT(25H0  HIN  (BTU/HR-FT**2-F)=,10F8.2)
            C*****PRINT THERMAL CONDUCTIVITIES
 0031             WRITE(6,14) IIM2,(XKZ(I),I=2,IIM2)                                      02443
 0032      14     FORMAT(5X,'THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ(',I3,')  FOL      02444
                 2LOW'/(5F10.2,5X,5F10.2))                                                02445
            C                                                                             02450
            C**PRINT THE DIMENSIONAL TEMPERATURES                                         02460
 0033             WRITE(6,11) T(1),IIM1,(T(I),I=2,IIM1)                                   02470
 0034      11     FORMAT( /35H0THE DIMENSIONAL TEMPERATURES ARE  /6H T(1)=,F10.2/         02480
                 213H T(2) THRU T(,I3,7H)  FOLLOW/(5F10.2,5X,5F10.2))                     02490
 0035             WRITE(6,13)II, T(II), T(IIP1)                                           02500
 0036      13     FORMAT(3H T(,I3,2H)=,F12.2,6X,7HT(AVE)=,F12.2)                          02510
            C                                                                             02520
            C**IF ANS(30).NE..0. PRINT THE DIMENSIONLESS TEMPERATURES                     02530
```

```
0037              WRITE(6,15)TSTAR(1),IIM1,(TSTAR(I),I=2,IIM1)                   02550
0038              WRITE(6,13) II,TSTAR(II), TSTAR(IIP1)                          02560
0039        15    FORMAT( /35HOTHE DIMENSIONLESS TEMPERATURES ARE/6H T(1)=,F10.2/  02570
                 213H T(2) THRU T(,I3,9H) FOLLOW/(5F10.3,5X,5F10.3))             02580
            C     PLOT OF AVG TEMP. VS TIME
0040              REAL DATAAX(150), DATAAY(150)
0041              ITIM = ITIM + 1
            C     TAVE = T(IIP1)
0042              TT(ITIM) = T(IIP1)
0043              TTM(ITIM) = T(2)
0044              TTO(ITIM) = T(IIM1)
0045              TIM(ITIM) = TAUT*TSEC
0046              IF(IPLOT(11) .EQ. 0) GO TO 18
0047              IF(ANS(IANS) .NE..0) GO TO 18
0048              DO 17 J = 1, ITIM
0049              DATAAY(J1) = TT(J)
0050              DATAAX(J1) = TIM(J)
0051          17  J1=J1+1
0052              IF(NSUP.EQ.0) GO TO 162
0053              IF(KOUNT.LT.(NSUP+1)) GO TO 18
0054         162  CALL GRAPH (ITIM, DATAAX, DATAAY, 3, 1, 8.0, 6.0, 0.0, 0.0,
                 20.0, 0.0, 'TIME SECONDS', 'TEMPERATURE (AVE) F',
                 2'TRANSIENT TEMP.', 'VARIOUS RADII')
0055              ITIM1=ITIM +1
0056              IF(NSUP.EQ.0) GO TO 18
0057              DO 161 IT=1,NSUP
0058              DO 160 I=1,ITIM
0059              DATX(I)=DATAAX(ITIM1)
0060              DATY(I)=DATAAY(ITIM1)
0061         160  ITIM1=ITIM1+1
0062         161  CALL GRAPH(ITIM,DATX,DATY,3,1,0.0,8.0,0.0,0.0,
                 20.0, 0.0, 'TIME SECONDS', 'TEMPERATURE (AVE) F',
                 2'TRANSIENT TEMP.', 'VARIOUS RADII')
0063        18    CONTINUE
            C     PLOT BORE TEMP. VS TIME
0064              IF(IPLOT(10) .EQ. 0) GO TO 19
0065              IF(ANS(IANS) .NE..0) GO TO 19
0066              REAL DATAXA(150), DATAYA(150)
0067              DO 21 J = 1,ITIM
0068              DATAYA(J2) = TTB(J)
0069              DATAXA(J2) = TIM(J)
0070          21  J2=J2+1
0071              IF(NSUP.EQ.0) GO TO 172
0072              IF(KOUNT.LT.(NSUP+1)) GO TO 19
0073         172  CALL GRAPH (ITIM, DATAXA, DATAYA, 3, 1, 8.0, 6.0, 0.0, 0.0, 0.0,
                 20.0, 'TIME SECONDS','TEMPERATURE (BORE) F',
                 2'TRANSIENT BORE TEMP','CALCULATED DATA')
0074              ITIM2=ITIM+1
0075              IF(NSUP.EQ.0) GO TO 19
0076              DO 171 IT=1,NSUP
0077              DO 170 I=1,ITIM
0078              DATX(I)=DATAXA(ITIM2)
0079              DATY(I)=DATAYA(ITIM2)
```

```
0080         173 ITIM2=ITIM2+1
0081         171 CALL GRAPH(ITIM+DATX+DATY+3+1+0.0+8.0+6.0+6.0+0.0+0.0+
                20.0+ 'TIME SECONDS'+'TEMPERATURE (BORE) F'+
                2'TRANSIENT BORE TEMP'+'CALCULATED DATA')
0082       19    CONTINUE
           C   PLOT BARREL EXTERNAL TEMP. VS TIME
0083             IF(IPLOT(9) .EQ. 0) GO TO 25
0084             IF(ANS(IANS) .NE..0) GO TO 25
0085             REAL DATAIX(150)+ DATAIY(150)
0086             DO 23 I = 1+ITIM
0087             DATAIY(J3) = TTO(J)
0088             DATAIX(J3) = TIM(J)
0089          23 J3=J3+1
0090             IF(NSUP.EQ.0) GO TO 212
0091             IF(KOUNT.LT.(NSUP+1)) GO TO 25
0092         212 CALL GRAPH (ITIM+ DATAIX+  DATAIY+  3+ 1+ 8.0+ 6.0+ 0.0+ 0.0+
                20.0+ 0.0+ 'TIME SECONDS'+'TEMPERATURE(EXTERNAL) F'+ '
                2TRANSIENT EXTERNAL TEMP.'+ 'CALCULATED DATA')
0093             ITIM3=ITIM+1
0094             IF(NSUP.EQ.0) GO TO 25
0095             DO 211 II=1+NSUP
0096             DO 210 I=1+ITIM
0097             DATX(I)=DATAIX(ITIM3)
0098             DATY(I)=DATAIY(ITIM3)
0099         210 ITIM3=ITIM3+1
0100         211 CALL GRAPH(ITIM+DATX+DATY+3+1+0.0+8.0+0.0+0.0+
                20.0+ 0.0+ 'TIME SECONDS'+'TEMPERATURE(EXTERNAL) F'+ '
                2TRANSIENT EXTERNAL TEMP.'+ 'CALCULATED DATA')
0101       25    CONTINUE
           C PLOT TEMP VS RADII
0102             REAL DATAX(150)+DATAY(150)
0103             IF(ANS(IANS) .NE..0) RETURN
0104             DO 16 I = 2+IIM1
0105             DATAY(J4)=T(I)
0106             DATAX(J4)=RI(I)
0107          16 J4=J4+1
0108             IF(NSUP.EQ.0) GO TO 232
0109             IF(KOUNT.LT.(NSUP+1)) GO TO 27
0110         232 CALL GRAPH (IIM2+ DATAX+ DATAY+ 3+ 1+ 8.0+ 8.0+ 0.0+ 0.0+ 0.0+0.0+
                2'RADIUS FT'+ 'TEMPERATURE F'+ 'THERMAL DATA '+ 'RADIAL TEMP.')
0111             ITIM4=IIM2+1
0112             IF(NSUP.EQ.0) GO TO 27
0113             DO 231 II=1+NSUP
0114             DO 230 I=1+IIM2
0115             DATX(I)=DATAX(ITIM4)
0116             DATY(I)=DATAY(ITIM4)
0117         230 ITIM4=ITIM4+1
0118         231 CALL GRAPH(IIM2+DATX+DATY+3+1+0.0+8.0+0.0+0.0+0.0+0.0+0.0+
                2'RADIUS FT'+ 'TEMPERATURE F'+ 'THERMAL DATA '+ 'RADIAL TEMP.')
           C                                                                  02590
0119       27    KOUNT = KOUNT + 1
0120             RETURN                                                       02870
0121             END                                                          02880
```

```
FORTRAN IV G LEVEL  21                RESULT            DATE = 75094          11/35/51            PAGE 0004

  *OPTIONS IN EFFECT*  *ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = RESULT  , LINECNT =       55
  *STATISTICS*    SOURCE STATEMENTS =       121,PROGRAM SIZE =    13794
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  21                TAVE                DATE = 75094         11/35/51               PAGE 0001

 0001              SUBROUTINE TAVE(II,IIP1)                                                      02890
 0002              COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)                02900
             C                                                                                   02910
             C**CALCULATE WEIGHTED AVERAGED TEMPERATURE AND STORE IT IN T(IIP1)                  02920
 0003              SUM = .0                                                                      02930
 0004              SUM2 = .0                                                                     02940
 0005              DO 39 I=1,II                                                                  02950
 0006              SUM = SUM + C(I)*T(I)                                                         02960
 0007        39    SUM2 = SUM2 + C(I)                                                            02970
 0008              T(IIP1) = SUM/SUM2                                                            02980
 0009              RETURN                                                                        02990
 0010              END                                                                           03000
```

```
FORTRAN IV G LEVEL  21                  TAVE              DATE = 75094         11/35/51            PAGE 0002

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = TAVE     , LINECNT =        55
  *STATISTICS*     SOURCE STATEMENTS =       10,PROGRAM SIZE =      442
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

FORTRAN IV G LEVEL 21 CHANGE DATE = 75094 11/35/51 PAGE 0001

```
      SUBROUTINE CHANGE (NBODY,TSEC,TAUT,II,I1,NNN)
      DIMENSION HZ(1),N1(1),N2(1)
      COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,P)
      COMMON /BLK2/ RADII(11),NODES(10),XKZ(150),BETA(10),CP(10),
     2RHO(10),EMISS,RHOZ,COZ,AKRZ,ROTR(11),RI(150),RII(150),DR(10),
     2A(9),ITB(11)
C
C     J     = NUMBER OF R'S WHICH ARE TEMP. OR TIME DEPENDENT
C     N1(J)= RESISTOR NUMBER -- N1(J) = J1
C     N2(J)= RESISTOR TYPE
C     HZ(J)= RESISTOR'S INITIAL VALUE
C     A     = ARRAY CONTAINING COEFFICIENTS FOR FUNCTIONS, EXPONENTS ETC.
C     TSEC = CONVERSION FACTOR (REAL TIME IN SECONDS = TIMEX*TSEC)
C     EXPO1= EXPONENT N WHERE H = HZ*ABS(T(J1) - T(J1+1))**EXPO1
C     ITB   = ARRAY CONTAINING TYPE KEY FOR ALL BOUNDARY RESISTORS
C     TYPE = 1   H = CONSTANT
C     TYPE = 2   H = HZ*F3(TIME)
C     TYPE = 3   H = HZ*(DT)**EXPO1
C     TYPE = 4   H = HR + HC
C     TYPE = 5 H = HZ*F5(TIME) -- F5 IS A PERODIC RECTANGULAR WAVE
C
C  STORE INITIAL VALUES AND DETERMINE WHICH RESISTORS ARE NOT OF TYPE 1
      IF(TAUT.GT..0) GO TO 1
      N=0
      N8 = IFIX( A(8) )
      N9 = IFIX( A(9) )
      TI = T(1)
      TII = T(II)
      HR = EMISS*.1714E-8/XKPZ
      EXPO1 = A(7)
      J = 0
      IF(ITB(1).EQ.1) GO TO 7
      J = 1
      N1(1) = 1
      N2(1) = ITB(1)
      HZ(1) = HX(1)
    7 DO 5 I=1,NBODY
      IF(ITB(I+1).EQ.1) GO TO 5
      J = J + 1
      N1(J) = IBODY(I,2)
      N2(J) = ITB(I+1)
      J1 = N1(J)
      HZ(J) = HX(J1)
    5 CONTINUE
C
C**POINT OF ENTRY FOR TIME.GT.ZERO -- CALCULATE NEW BDY TEMPERATURES
    1 TIME = TAUT*TSEC
      T(1) = TI*(1. + A(1)*SIN(A(2)*TIME))
C
      T(II) = TII*(1. + TIME*(A(3) + A(4)*TIME))
C**IF ALL H'S ARE CONSTANTS RETURN OTHERWISE RECALCULATE THOSE CHANGING
      IF(J.EQ.0) RETURN
      DO 11 I=1,J
```

```
FORTRAN IV G LEVEL  21                 CHANGE             DATE = 75094          11/35/51              PAGE 0002

 0032                 J1 = N1(I)                                                              03530
 0033                 DTEMP = ABS(T(J1)-T(J1+1))                                              03540
 0034                 IF(DTEMP.EQ.0.) DTEMP=1.                                                03550
 0035                 M = MZ(I)                                                               03560
 0036                 GO TO (11,12,13,14,15,16,17),M                                          03570
 0037           12    IF(TIME.GT. 0.) GO TO 11
 0038                 MX(J1) = MZ(I)-A(5)*TIME*RADII(J1)/XKR2                                 03585
 0039                 GO TO 11                                                                03590
 0040           13    MX(J1) = MZ(I)  *       DTEMP            **EXPO1                        03600
 0041                 GO TO 11                                                                03610
 0042           14    TA = T(J1) + 460.                                                       03620
 0043                 TB = T(J1+1) + 460.                                                     03630
 0044                 MX(J1) =  MB*RI(J1)      *(TA**2 + TB**2)*(TA + TB)                     03640
                     2  * MZ(I) * DTEMP ** EXPO1                                              03650
 0045                 GO TO 11                                                                03660
 0046           15    IF(N.EQ.0) MX(J1) = MZ(I) * A(5)                                        03670
 0047                 IF(N.EQ.N8) MX(J1) = MZ(I)                                              03680
 0048                 IF(N.EQ.N9) N =-1                                                       03690
 0049                 N = N + 1                                                               03700
 0050                 GO TO 11                                                                03710
 0051           16    GO TO 11                                                                03720
 0052           17    GO TO 11                                                                03730
 0053           11    CONTINUE                                                                03740
 0054                 NN1 = NNN + 1                                                           03750
 0055                 IF((MOD(NN1,IX).NE.0).OR.(J.EQ.0)) RETURN                               03760
 0056                 DO 21 I=1,J                                                             03770
 0057                 J1 = N1(I)                                                              03780
 0058           21    T(J1+1+1) = MX(J1) * XKR2 / RI(J1)                                      03790
 0059                 RETURN                                                                  03800
 0060                 END                                                                     03810
```

```
FORTRAN IV G LEVEL  21                    CHANGE            DATE = 75094          11/35/51              PAGE 0003

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = CHANGE  , LINECNT =       55
  *STATISTICS*    SOURCE STATEMENTS =       60,PROGRAM SIZE =     1952
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
0001           BLOCK DATA                                                          03820
          C                                                                        03830
          C***INITIALIZATION OF LABELED COMMON TO DEFAULT VALUES                   03840
0002           COMMON /BLK1/ T(150),C(150),CX(150),H(150),HX(150),IBODY(10,2)      03850
0003           COMMON /BLK2/ RADII(11),NODES(10),XKZ(150),BETA(10),CP(10),         03860
              2RHO(10),EMISS,RHOZ,CPZ,XKRZ,BDYR(11),PI(150),RII(150),DR(10),       03870
              2A(9),ITB(11)                                                        03871
0004           COMMON /BLK3/ TY(500,10),TAU(500),Q(500),ISYM,XMIN,XMAX,YMIN,YMAX,  03880
              2IPLOT(11), TIM(150),TTR(150) , TTO(150) ,TS(150)                    03881
0005           COMMON /BLK4/ KOUNT,J1,J2,J3,J4,NSUP
0006           DATA ISYM,XMIN,XMAX,YMIN,YMAX,EMISS,RHOZ,CPZ,XKRZ,XKZ,BETA,CP,RHO/  03890
              2 2, .0, 1., .0, 1., 1., 490.,.11, 10.,150*10., 10*.0,10*.11,10*490  03900
              3./,NODES,T,BDYR/10*5, 1.,149*.0,11*.0/,A,ITB/6*.0,    3*.0,11*1     03910
              4/,IPLOT/8*0,1,1,1/,NSUP/0/
0007           END                                                                 03920
```

```
*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = BLK DATA, LINECNT =       55
*STATISTICS*  NO DIAGNOSTICS GENERATED

*STATISTICS*  NO DIAGNOSTICS THIS STEP
```

```
F6A-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED LIST,LET,NOXREF,SCTR
         DEFAULT OPTION(S) USED -   SIZE=(92160,8192)
****MAIN       DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET
```

| TIMEF | F |
|---|---|
| 0.0 | 1.00000 |
| 2.50000 | 1.00000 |
| 2.51000 | 0.0 |
| 30.00000 | 0.0 |
| 30.00999 | 1.00000 |
| 32.50000 | 1.00000 |
| 32.50999 | 0.0 |
| 60.00000 | 0.0 |
| 60.00999 | 1.00000 |
| 62.50000 | 1.00000 |
| 62.50999 | 0.0 |
| 90.00000 | 0.0 |
| 90.00999 | 1.00000 |
| 92.50000 | 1.00000 |
| 92.50999 | 0.0 |
| 120.00000 | 0.0 |
| 120.00999 | 1.00000 |
| 122.50000 | 1.00000 |
| 122.50999 | 0.0 |
| 150.00000 | 0.0 |
| 150.00999 | 1.00000 |
| 152.50000 | 1.00000 |
| 152.50999 | 0.0 |
| 180.00000 | 0.0 |
| 180.00999 | 1.00000 |
| 182.50000 | 1.00000 |
| 182.50999 | 0.0 |
| 210.00000 | 0.0 |
| 210.00999 | 1.00000 |
| 212.50000 | 1.00000 |
| 212.50999 | 0.0 |
| 240.00000 | 0.0 |
| 240.00999 | 1.00000 |
| 242.50000 | 1.00000 |
| 242.50999 | 0.0 |
| 270.00000 | 0.0 |
| 270.01001 | 1.00000 |
| 272.50000 | 1.00000 |
| 272.51001 | 0.0 |
| 300.00000 | 0.0 |
| 300.01001 | 1.00000 |
| 302.50000 | 1.00000 |
| 302.51001 | 0.0 |
| 330.00000 | 0.0 |
| 330.01001 | 1.00000 |
| 332.50000 | 1.00000 |
| 332.51001 | 0.0 |
| 360.00000 | 0.0 |
| 360.01001 | 1.00000 |
| 362.50000 | 1.00000 |
| 362.51001 | 0.0 |
| 390.00000 | 0.0 |
| 390.01001 | 1.00000 |
| 392.50000 | 1.00000 |
| 392.51001 | 0.0 |
| 420.00000 | 0.0 |
| 420.01001 | 1.00000 |
| 422.50000 | 1.00000 |

| | |
|---|---|
| 422.51001 | 0.0 |
| 450.00000 | 0.0 |
| 450.01001 | 1.00000 |
| 452.50000 | 1.00000 |
| 452.51001 | 0.0 |
| 540.00000 | 0.0 |
| 540.01001 | 1.00000 |
| 542.50000 | 1.00000 |
| 542.51001 | 0.0 |
| 570.00000 | 0.0 |
| 570.01001 | 1.00000 |
| 572.50000 | 1.00000 |
| 572.51001 | 0.0 |
| 600.00000 | 0.0 |
| 600.01001 | 1.00000 |
| 602.50000 | 1.00000 |
| 602.51001 | 0.0 |
| 630.00000 | 0.0 |
| 630.01001 | 1.00000 |
| 632.50000 | 1.00000 |
| 632.51001 | 0.0 |
| 660.00000 | 0.0 |
| 660.01001 | 1.00000 |
| 662.50000 | 1.00000 |
| 662.51001 | 0.0 |
| 690.00000 | 0.0 |
| 690.01001 | 1.00000 |
| 692.50000 | 1.00000 |
| 692.51001 | 0.0 |
| 720.00000 | 0.0 |
| 720.01001 | 1.00000 |
| 722.50000 | 1.00000 |
| 722.51001 | 0.0 |
| 750.00000 | 0.0 |
| 750.01001 | 1.00000 |
| 752.50000 | 1.00000 |
| 752.51001 | 0.0 |
| 780.00000 | 0.0 |
| 780.01001 | 1.00000 |
| 782.50000 | 1.00000 |
| 782.51001 | 0.0 |
| 810.00000 | 0.0 |
| 810.01001 | 1.00000 |
| 812.50000 | 1.00000 |
| 812.51001 | 0.0 |
| 840.00000 | 0.0 |
| 840.01001 | 1.00000 |
| 842.50000 | 1.00000 |
| 842.51001 | 0.0 |
| 870.00000 | 0.0 |
| 870.01001 | 1.00000 |
| 872.50000 | 1.00000 |
| 872.51001 | 0.0 |
| 900.00000 | 0.0 |
| 900.01001 | 1.00000 |
| 902.50000 | 1.00000 |
| 902.51001 | 0.0 |
| 930.00000 | 0.0 |
| 930.01001 | 1.00000 |
| 932.50000 | 1.00000 |

| | |
|---|---|
| 932.51001 | 0.0 |
| 960.00000 | 0.0 |
| 960.01001 | 1.00000 |
| 962.50000 | 1.00000 |
| 962.51001 | 0.0 |
| 990.00000 | 0.0 |
| 990.01001 | 1.00000 |
| 992.50000 | 1.00000 |
| 992.51001 | 0.0 |
| 1080.00000 | 0.0 |
| 1080.01001 | 1.00000 |
| 1082.50000 | 1.00000 |
| 1082.51001 | 0.0 |
| 1110.00000 | 0.0 |
| 1110.01001 | 1.00000 |
| 1112.50000 | 1.00000 |
| 1112.51001 | 0.0 |
| 1140.00000 | 0.0 |
| 1140.01001 | 1.00000 |
| 1142.50000 | 1.00000 |
| 1142.51001 | 0.0 |
| 1170.00000 | 0.0 |
| 1170.01001 | 1.00000 |
| 1172.50000 | 1.00000 |
| 1172.51001 | 0.0 |
| 1200.00000 | 0.0 |
| 1200.01001 | 1.00000 |
| 1202.50000 | 1.00000 |
| 1202.51001 | 0.0 |
| 1230.00000 | 0.0 |
| 1230.01001 | 1.00000 |
| 1232.50000 | 1.00000 |
| 1232.51001 | 0.0 |
| 1260.00000 | 0.0 |
| 1260.01001 | 1.00000 |
| 1262.50000 | 1.00000 |
| 1262.51001 | 0.0 |
| 1290.00000 | 0.0 |
| 1290.01001 | 1.00000 |
| 1292.50000 | 1.00000 |
| 1292.51001 | 0.0 |
| 1320.00000 | 0.0 |
| 1320.01001 | 1.00000 |
| 1322.50000 | 1.00000 |
| 1322.51001 | 0.0 |
| 1350.00000 | 0.0 |
| 1350.01001 | 1.00000 |
| 1352.50000 | 1.00000 |
| 1352.51001 | 0.0 |
| 1380.00000 | 0.0 |
| 1380.01001 | 1.00000 |
| 1382.50000 | 1.00000 |
| 1382.51001 | 0.0 |
| 1410.00000 | 0.0 |
| 1410.01001 | 1.00000 |
| 1412.50000 | 1.00000 |
| 1412.51001 | 0.0 |
| 1440.00000 | 0.0 |
| 1440.01001 | 1.00000 |
| 1442.50000 | 1.00000 |

| | |
|---|---|
| 1442.51001 | 0.0 |
| 1470.00000 | 0.0 |
| 1470.01001 | 1.00000 |
| 1472.50000 | 1.00000 |
| 1472.51001 | 0.0 |
| 1500.00000 | 0.0 |
| 1500.01001 | 1.00000 |
| 1502.50000 | 1.00000 |
| 1502.51001 | 0.0 |
| 1530.00000 | 0.0 |
| 1530.01001 | 1.00000 |
| 1532.50000 | 1.00000 |
| 1532.51001 | 0.0 |
| 1700.00000 | 0.0 |

```
HEAT TRANSFER PROGRAM HT-2A
PROGRAMMED BY A.M.CLAUSING
CRANK-NICOLSON ALGORITHM
VERSION = 1 JULY 1970


THE INPUT PARAMETERS ARE
&NAM1
DTIMEX=  .499999849E-03,DDTX=  .250000000    ,DZ=  .386000015E-01,II=          17,NBODY=            1,IX=              3,XKRZ=
  15.0000000     ,RHOZ=  490.000000     ,CPZ=  .110000014     ,EMISS=  .500000000     ,TNUM=  .0                    ,TDENOM=  1.00000000    ,
ISYM=            0,XMAX=  1.00000000     ,XMIN=  .0                  ,YMAX=  1.00000000     ,YMIN=  .0                    ,NPLOT=          0,
         0,              0,              0,              0,              0,              0,              0,              0,              0,NODES=
        15.              5.              5.              5.              5.              5.              5.              5.              5,ANS=
 -1.00000000     ,  5.00000000     ,  10.0000000     ,  20.0000000     ,  30.0000000     ,  40.0000000     ,  50.0000000     ,
  60.0000000     ,  70.0000000     ,  80.0000000     ,  90.0000000     ,  120.000000     ,  150.000000     ,  180.000000     ,
  210.000000     ,  240.000000     ,  260.000000     ,  300.000000     ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,X=  .0           ,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,  .0             ,  .0             ,ITB=             1,              4,              1,              1,              1,              1,
         1.              1.              1.              1.              1,IPLOT=        0,              0,              0,              0,              0,
         0.              0.              0.              1.              1.               1
&END

REGION    IBODY   RADII(FT)    DR(FT)      BDYR(FT)      CP        RHO        KZ     BETA
  1        2  16  0.124E-01  0.353E-02  0.267E-01    0.110      490.0      15.0   0.0
  2               0.618E-01             0.150E+02

  I       H(I)            C(I)            T(I)        RADIUS
  1     0.4644E+00      0.0              1563.00      0.01240
  2     0.4014E+01      0.1573E-01        80.00       0.01240
  3     0.5014E+01      0.3772E-01        80.00       0.01593
  4     0.6014E+01      0.4608E-01        80.00       0.01946
  5     0.7014E+01      0.5444E-01        80.00       0.02299
  6     0.8014E+01      0.6279E-01        80.00       0.02651
  7     0.9014E+01      0.7115E-01        80.80       0.03004
  8     0.1001E+02      0.7950E-01        80.00       0.03357
  9     0.1101E+02      0.8786E-01        80.00       0.03710
 10     0.1201E+02      0.9622E-01        80.00       0.04063
 11     0.1301E+02      0.1046E+00        80.00       0.04416
 12     0.1401E+02      0.1129E+00        80.00       0.04769
 13     0.1501E+02      0.1213E+00        80.00       0.05121
 14     0.1601E+02      0.1296E+00        80.00       0.05474
 15     0.1701E+02      0.1380E+00        80.00       0.05827
 16     0.4120E-02      0.7213E-01        80.00       0.06180
 17     0.0             0.0               80.00       0.06180
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DIMENSIONLESS TIME =  0.052          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.100E+01   QIN=   0.501E+05  QOUT=   0.118E-01    HR+HC=   0.154E+01   HR=   0.540E+00

   SUMQIN=  15.05021           SUMQSTR=  54.86342            SUMQOUT=   0.00000           ENERGY BALANCE=-264.53564

 M VALUES FOR REGIONS 1 THRU NBODY ARE 16.71
  MIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR KKZ(2) THRU KKZ( 15)  FOLLOW
    24.47     25.75     26.47     26.94     27.23          27.41     27.51     27.56     27.58     27.59
    27.60     27.60     27.60     27.60

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
   418.80     294.50    211.27     157.03     123.13          102.98     91.63     85.58     82.55     81.10
    80.45      80.18     80.07      80.03      80.02
T( 17)=       80.00       T(AVE)=       104.28

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  418.707   294.504   211.270   157.030   123.131         102.976    91.625    85.583    82.546    81.103
   80.455    80.180    80.070    80.029    80.020
T( 17)=       80.00       T(AVE)=       104.28

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0010
THE CURRENT DIMENSIONLESS TIME IS = 0.2505


DIMENSIONLESS TIME =  0.259          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.500E+01   QIN=   0.422E+05  QOUT=   0.170E+02    HR+HC=   0.158E+01   HR=   0.582E+00

   SUMQIN=  65.22284           SUMQSTR=  97.91985            SUMQOUT=   0.00594           ENERGY BALANCE= -50.14029

 M VALUES FOR REGIONS 1 THRU NBODY ARE  8.36
  MIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR KKZ(2) THRU KKZ( 15)  FOLLOW
    23.10     24.06     24.80     25.38     25.84          26.21     26.51     26.75     26.94     27.08
    27.19     27.27     27.32     27.36

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
   597.76     487.78    403.29     336.65     283.37          240.58    206.25    178.85    157.23    140.45
   127.76     118.56    112.18     108.85     107.71
T( 17)=       80.00       T(AVE)=       105.13

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  597.763   487.777   403.291   336.646   283.374         240.584   206.247   178.852   157.231   140.451
  127.761   118.562   112.377   108.845   107.707
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T( 17)=       80.00      T(AVE)=      185.13

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0020
THE CURRENT DIMENSIONLESS TIME IS = 0.5005



 DIMENSIONLESS TIME =  2.520           HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.103E+02   QIN=   0.387E+05  QOUT=   0.746E+02    HR+HC=   0.173E+01   HR=   0.729E+00

    SUMQIN= 121.53964          SUMQSTR= 148.45602           SUMQOUT=   0.06755          ENERGY BALANCE= -22.20175

 K VALUES FOR REGIONS 1 THRU NBODY ARE  4.18
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    22.49     23.28     23.97     24.52     24.97          25.35     25.66     25.92     26.13     26.29
    26.42     26.52     26.59     26.63

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
   678.98    577.68    498.67    435.07    382.96         339.89    304.20    274.75    250.67    231.33
   216.22    204.95    197.18    192.66    191.17
T( 17)=       80.00      T(AVE)=      275.77

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  678.981   577.681   498.666   435.067   382.959        339.886   304.201   274.748   250.674   231.334
  216.224   204.947   197.180   192.659   191.169
T( 17)=       80.00      T(AVE)=      275.77

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0040
THE CURRENT DIMENSIONLESS TIME IS = 1.0005



 DIMENSIONLESS TIME =  1.040           HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.201E+02   QIN=   0.337E+05  QOUT=   0.232E+03    HR+HC=   0.212E+01   HR=   0.1;2E+01

    SUMQIN= 222.10065          SUMQSTR= 239.08818           SUMQOUT=   0.48493          ENERGY BALANCE=  -7.86691

 K VALUES FOR REGIONS 1 THRU NBODY ARE  2.09
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    21.42     22.19     22.79     23.27     23.67          24.00     24.28     24.51     24.70     24.85
    24.97     25.06     25.12     25.16

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
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   792.10    703.70    634.59    578.79    532.93        494.86    463.19    436.93    415.36    397.94
   384.27    374.01    366.90    362.71    361.26
T( 17)=       80.00      T(AVE)=      437.10

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  792.105   703.695   634.543   578.794   532.927       494.862   463.190   436.926   415.355   397.942
  384.270   374.011   366.809   362.712   361.263
T( 17)=       80.00      T(AVE)=      437.10



DIMENSIONLESS TIME =  1.563          HEAT FLOW PER FT (BTU/HR-FT)           COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.301E+02   QIN=   0.295E+05  QOUT=   0.433E+03    HR+HC=   0.259E+01   HR=   0.159E+01

   SUMQIN= 309.98145            SUMQSTR= 317.85913            SUMQOUT=   1.40301            ENERGY BALANCE=  -2.99389

 N VALUES FOR REGIONS 1 THRU NROOT ARE  2.00
  MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XK2(2) THRU XK2( 15)  FOLLOW
   20.58     21.25     21.78     22.20     22.55        22.84     23.09     23.29     23.45     23.58
   23.49     23.77     23.82     23.86

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  888.78    811.00    750.50    701.66    661.48        628.12    600.35    577.30    558.34    543.02
  530.96    521.89    515.54    511.75    510.35
T( 17)=      80.00      T(AVE)=      577.26

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  888.378   811.003   750.504   701.656   661.480       628.121   600.346   577.295   558.343   543.018
  530.958   521.876   515.538   511.750   510.349
T( 17)=      80.00      T(AVE)=      577.26

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0080
THE CURRENT DIMENSIONLESS TIME IS = 2.0004



DIMENSIONLESS TIME =  2.082          HEAT FLOW PER FT (BTU/HR-FT)           COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.401E+02   QIN=   0.259E+05  QOUT=   0.674E+03    HR+HC=   0.310E+01   HR=   0.210E+01

   SUMQIN= 386.41895            SUMQSTR= 386.16479            SUMQOUT=   2.03897            ENERGY BALANCE=  -0.56467

 N VALUES FOR REGIONS 1 THRU NROOT ARE  1.04
  MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XK2(2) THRU XK2( 15)  FOLLOW
   19.85     20.45     20.91     21.24     21.49        21.84     22.06     22.23     22.38     22.50
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   22.53      22.46      22.71      22.74

 THE DIMENSIONAL TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)  FOLLOW
   971.02     904.12     851.10     808.27     773.03          743.75     719.35     699.07     682.38     668.85
   658.17     650.06     644.39     640.91     639.51
 T( 17)=       80.00        T(AVE)=       698.60

 THE DIMENSIONLESS TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)  FOLLOW
   971.023    904.125    851.100    808.271    773.028         743.747    719.347    699.073    682.377    668.848
   658.160    650.079    644.383    640.906    639.507
 T( 17)=       80.00        T(AVE)=       698.60


  DIMENSIONLESS TIME =  2.600           HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
  REAL TIME (SECONDS)=  0.501E+02   QIN=   0.227E+05  QOUT=   0.944E+03    HR+HC=   0.363E+01   HR=   0.263E+01

    SUMQIN= 454.35742           SUMQSTR= 445.24876            SUMQOUT=   5.19321            ENERGY BALANCE=   0.86177

  H VALUES FOR REGIONS 1 THRU NBODY ARE  1.04
   HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    19.22      19.74      20.15      20.48      20.75          20.97      21.16      21.31      21.44      21.55
    21.63      21.69      21.74      21.77

 THE DIMENSIONAL TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)  FOLLOW
   1044.27    984.76     938.21     900.58     869.60          843.84     822.35     804.46     789.70     777.70
    768.16    760.93     755.76     752.51     751.08
 T( 17)=       80.00        T(AVE)=       803.93

 THE DIMENSIONLESS TEMPERATURES ARE
 T(1)=   1563.00
 T(2) THRU T( 16)  FOLLOW
  1044.271    984.764    938.208    900.583    869.603         843.840    822.347    804.459    789.697    777.696
   768.162    760.928    755.755    752.515    751.080
 T( 17)=       80.00        T(AVE)=       803.93


  DIMENSIONLESS TIME =  3.125           HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
  REAL TIME (SECONDS)=  0.601E+02   QIN=   0.200E+05  QOUT=   0.124E+04    HR+HC=   0.416E+01   HR=   0.316E+01

    SUMQIN= 513.60229           SUMQSTR= 496.19019            SUMQOUT=   8.23736            ENERGY BALANCE=   1.78636

  H VALUES FOR REGIONS 1 THRU NBODY ARE  1.04
   HIN  (BTU/HR-FT**2-F)=  561.80
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   THERMAL CONDUCTIVITIES FOR KKZ(2) THRU KKZ( 15)  FOLLOW
   18.48     19.14     19.49     19.78     20.02          20.22     20.38     20.52     20.64     20.73
   20.80     20.86     20.90     20.93

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1503.00
T(2) THRU T( 16)  FOLLOW
  1106.73   1054.38   1013.40    980.27    952.98          930.22    911.22    895.38    882.26    871.56
   863.72    856.47    851.72    848.65    847.15
T( 17)=      80.00      T(AVE)=      894.50

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1106.770  1054.379  1013.402   980.266   952.456         930.219   911.221   895.377   882.264   871.564
  863.031   856.469   851.720   848.652   847.154
T( 17)=      80.00      T(AVE)=      894.54


 DIMENSIONLESS TIME =  3.632         HEAT FLOW PER FT (BTU/HR-FT)         COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.700E+07   QIN=   2.177E+05  QOUT=   0.154E+04     HR+HC=   0.466E+01   HR=   0.366E+01

    SUMQIN= 565.03174             SUTASTR= 539.35571            SUMQOUT=  12.04518             ENERGY BALANCE=   2.41241
 * VALUES FOR REGIONS 1 THRU NROOT ARE  1.04
  HIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR KKZ(2) THRU KKZ( 15)  FOLLOW
    18.22     18.62     18.96     19.19     19.40          19.58     19.73     19.85     19.95     20.04
    20.10     20.15     20.19     20.22

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1159.73   1113.45   1077.20   1047.86   1023.46         1003.46    986.59    972.46    960.73    951.12
   943.40    937.40    932.98    930.06    928.45
T( 17)=      80.00      T(AVE)=      971.40

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1159.725  1113.445  1077.190  1047.863  1023.450        1003.480   986.586   972.462   960.733   951.116
  943.396   937.399   932.936   930.035   928.454
T( 17)=      80.00      T(AVE)=      971.40

TIME INCREMENT DOUBLED. NEW DIMENSIONLESS INCREMENT IS = 0.0160
THE CURRENT DIMENSIONLESS TIME IS = 4.0001


 DIMENSIONLESS TIME =  4.160         HEAT FLOW PER FT (BTU/HR-FT)         COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
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REAL TIME (SECONDS)=  0.302E+02   QIN=   0.156E+05  QOUT=   0.184E+04    HR+HC=   0.514E+01   HR=   0.414E+01

   SUMQIN= 511.88949          SUMQSTR= 577.51367          SUMQOUT=  15.82306          ENERGY BALANCE=   2.86869

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
  HIN  (BTU/HR-FT**2-F)=  561.90
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   17.91     18.17     18.45     18.68     18.87          19.02     19.15     19.26     19.35     19.43
   19.49     19.54     19.58     19.60

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1206.63   1165.72   1133.66   1107.68   1086.23        1068.30   1053.26   1040.65   1030.13   1021.45
  1014.43   1008.92   1004.78   1001.91   1000.23
T( 17)=        80.00       T(AVE)=      1039.31

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1206.627  1165.719  1133.657  1107.684  1086.226        1068.302  1053.261  1040.646  1030.127  1021.454
 1014.435  1008.917  1004.777  1001.911  1000.233
T( 17)=        80.00       T(AVE)=      1039.31
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DIMENSIONLESS TIME =  4.672          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.901E+02   QIN=   0.139E+05  QOUT=   0.212E+04    HR+HC=   0.558E+01   HR=   0.458E+01

   SUMQIN= 652.17725          SUMQSTR= 609.14966          SUMQOUT=  22.26405          ENERGY BALANCE=   3.18375

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
  HIN  (BTU/HR-FT**2-F)=  561.20
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   17.47     17.79     18.04     18.24     18.41          18.55     18.67     18.77     18.85     18.92
   18.98     19.02     19.06     19.08

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1245.56   1209.11   1180.52   1157.33   1138.14        1122.08   1108.57   1097.20   1087.67   1079.77
  1073.32   1068.19   1064.26   1061.44   1059.66
T( 17)=        80.00       T(AVE)=      1095.61

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1245.561  1209.110  1180.519  1157.331  1138.144        1122.084  1108.573  1097.201  1087.675  1079.772
 1073.321  1068.187  1064.258  1061.443  1059.664
T( 17)=        80.00       T(AVE)=      1095.61
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DIMENSIONLESS TIME =  5.243          HEAT FLOW PER FT (BTU/HR-FT)           COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  5.120E+03   QIN=   0.101E+05  QOUT=   0.288E+04    HR+HC=   0.667E+01   HR=   0.567E+01

   SUMQIN= 751.33954           SUMQSTR= 679.94305            SUMQOUT=  43.43138            ENERGY BALANCE=   3.71696

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
  MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   16.71     16.94     17.12     17.27     17.39         17.50     17.59     17.66     17.72     17.78
   17.82     17.86     17.89     17.92

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1332.87   1306.41   1285.59   1268.64   1254.52        1242.62   1232.50   1223.88   1216.54   1210.31
  1205.08   1200.75   1197.23   1194.47   1192.39
T( 17)=       80.00       T(AVE)=    1221.61

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1332.847  1306.411  1285.594  1268.635  1254.520      1242.615  1232.500  1223.879  1216.537  1210.313
 1205.084  1200.751  1197.234  1194.467  1192.393
T( 17)=       80.00       T(AVE)=    1221.61
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DIMENSIONLESS TIME =  7.792          HEAT FLOW PER FT (BTU/HR-FT)           COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.150E+03   QIN=   0.777E+04  QOUT=   0.343E+04    HR+HC=   0.740E+01   HR=   0.640E+01

   SUMQIN= 824.51929           SUMQSTR= 722.51904            SUMQOUT=  69.79770            ENERGY BALANCE=   3.90563

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.52
  MIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   16.75     16.63     16.57     16.68     16.76         16.86     16.93     16.99     17.05     17.09
   17.13     17.17     17.19     17.22

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1385.51   1365.08   1348.94   1335.73   1324.65        1315.23   1307.14   1300.15   1294.10   1288.85
  1284.32   1280.43   1277.11   1274.32   1272.02
T( 17)=       80.00       T(AVE)=    1297.40

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1385.510  1365.077  1348.940  1335.726  1324.654      1315.235  1307.145  1300.153  1294.096  1288.850
 1284.319  1280.426  1277.112  1274.323  1272.020
T( 17)=       80.00       T(AVE)=    1297.40

TIME INCREMENT DOUBLED, NEW DIMENSIONLESS INCREMENT IS = 0.0320
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```
THE CURRENT DIMENSIONLESS TIME IS = 8.0002


 DIMENSIONLESS TIME =  9.344          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.130E+03   QIN=   0.638E+04  QOUT=   0.379E+04    HR+HC=   0.787E+01   HR=   0.687E+01

    SUMQIN= 882.70020          SUMQSTR= 748.12891          SUMQOUT=  99.90506          ENERGY BALANCE=   3.92730

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  HIN   (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.97     16.12     16.24     16.33     16.41        16.48     16.54     16.60     16.64     16.68
    16.72     16.75     16.78     16.80

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1417.22   1400.42   1387.09   1376.13   1366.89       1358.96   1352.08   1346.06   1340.77   1336.10
  1331.98   1328.33   1325.12   1322.30   1319.84
T( 17)=        80.00       T(AVE)=      1342.90

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1417.221  1400.415  1387.094  1376.132  1366.898       1358.960  1352.082  1346.064  1340.772  1336.102
 1331.977  1328.334  1325.124  1322.304  1319.841
T( 17)=        80.00       T(AVE)=      1342.90



 DIMENSIONLESS TIME = 10.912          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.210E+03   QIN=   0.555E+04  QOUT=   0.402E+04    HR+HC=   0.817E+01   HR=   0.717E+01

    SUMQIN= 932.38144          SUMQSTR= 763.50000          SUMQOUT= 132.78827          ENERGY BALANCE=   3.87113

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  HIN   (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.81     15.93     16.04     16.12     16.19        16.25     16.31     16.35     16.40     16.43
    16.47     16.50     16.52     16.55

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1434.28   1421.66   1410.03   1400.42   1392.27       1385.23   1379.08   1373.64   1368.80   1364.47
  1360.58   1357.08   1353.93   1351.08   1348.51
T( 17)=        80.00       T(AVE)=      1370.36

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
```

```
 1436.282  1421.658  1410.928  1400.418  1392.269       1385.233  1379.079  1373.640  1368.801  1364.471
 1360.582  1357.082  1353.926  1351.079  1348.512
T( 17)=       80.00       T(AVE)=      1370.36


 DIMENSIONLESS TIME = 12.494          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  3.241E+03   QIN=   0.505E+04  QOUT=   0.416E+04    HR+HC=   0.834E+01   HR=   0.734E+01

    SUMQIN= 976.65063           SUMQSTR= 772.54980          SUMQOUT= 167.21022          ENERGY BALANCE=   3.77726

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.24
  MIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.71      15.82      15.92      15.99      16.06          16.12      16.17      16.21      16.25      16.29
    16.32      16.35      16.38      16.40

 THE DIMENSIONAL TEMPERATURES ARE
 T(1)=    1563.00
 T(2) THRU T( 16)  FOLLOW
   1447.52    1434.18    1423.54    1414.73    1407.23          1400.71    1394.99    1389.89    1385.31    1381.18
   1377.43    1374.01    1370.88    1368.02    1365.39
 T( 17)=       80.00       T(AVE)=      1386.48

 THE DIMENSIONLESS TEMPERATURES ARE
 T(1)=    1563.00
 T(2) THRU T( 16)  FOLLOW
  1447.517  1434.177  1423.543  1414.729  1407.225       1400.715  1394.986  1389.887  1385.312  1381.180
  1377.429  1374.010  1370.884  1368.019  1365.387
 T( 17)=       80.00       T(AVE)=      1386.48


 DIMENSIONLESS TIME = 13.504          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
 REAL TIME (SECONDS)=  0.260E+03   QIN=   0.485E+04  QOUT=   0.422E+04    HR+HC=   0.842E+01   HR=   0.742E+01

    SUMQIN=1003.74585           SUMQSTR= 776.32959          SUMQOUT= 190.21936          ENERGY BALANCE=   3.70582

 M VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  MIN  (BTU/HR-FT**2-F)=  561.80
    THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
    15.67      15.78      15.87      15.94      16.00          16.06      16.11      16.15      16.19      16.22
    16.26      16.29      16.31      16.34

 THE DIMENSIONAL TEMPERATURES ARE
 T(1)=    1563.00
 T(2) THRU T( 16)  FOLLOW
   1452.21    1439.41    1429.19    1420.71    1413.47          1407.18    1401.63    1396.67    1392.21    1388.16
   1384.47    1381.08    1377.97    1375.09    1372.44
 T( 17)=       80.00       T(AVE)=      1393.22

 THE DIMENSIONLESS TEMPERATURES ARE
```

```
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1452.210  1439.407  1429.191  1420.710  1413.475      1407.163  1401.631  1396.674  1392.210  1388.160
 1384.466  1381.081  1377.967  1375.093  1372.435
T( 17)=        80.00       T(AVE)=      1393.22


DIMENSIONLESS TIME = 15.564          HEAT FLOW PER FT (BTU/HR-FT)          COMBINED CONVECTION COEFFICIENT (BTU/HR-FT**2-F)
REAL TIME (SECONDS)=  0.300E+03   QIN=   0.460E+04  QOUT=   0.??E+04    HR+HC=   0.851E+01   HR=   0.752E+01

   SUMQIN=1056.1650*          SUMQSTR= 780.92163          SUMQOUT= 237.73306          ENERGY BALANCE=   3.55157

 * VALUES FOR REGIONS 1 THRU NBODY ARE  0.26
  HIN  (BTU/HR-FT**2-F)=  561.80
   THERMAL CONDUCTIVITIES FOR XKZ(2) THRU XKZ( 15)  FOLLOW
   15.62      15.72      15.81      15.88      15.94          15.99      16.04      16.08      16.12      16.15
   16.18      16.21      16.24      16.26

THE DIMENSIONAL TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
  1457.02    1445.77    1436.06    1427.98    1421.07        1415.05    1409.71    1404.93    1400.60    1396.65
  1393.02    1389.68    1386.58    1383.69    1381.00
T( 17)=        80.00       T(AVE)=      1401.41

THE DIMENSIONLESS TEMPERATURES ARE
T(1)=   1563.00
T(2) THRU T( 16)  FOLLOW
 1457.919  1445.770  1436.040  1427.982  1421.074      1415.049  1409.713  1404.928  1400.598  1396.648
 1393.072  1389.677  1386.577  1383.693  1381.000
T( 17)=        80.00       T(AVE)=      1401.41
```

APPENDIX 3

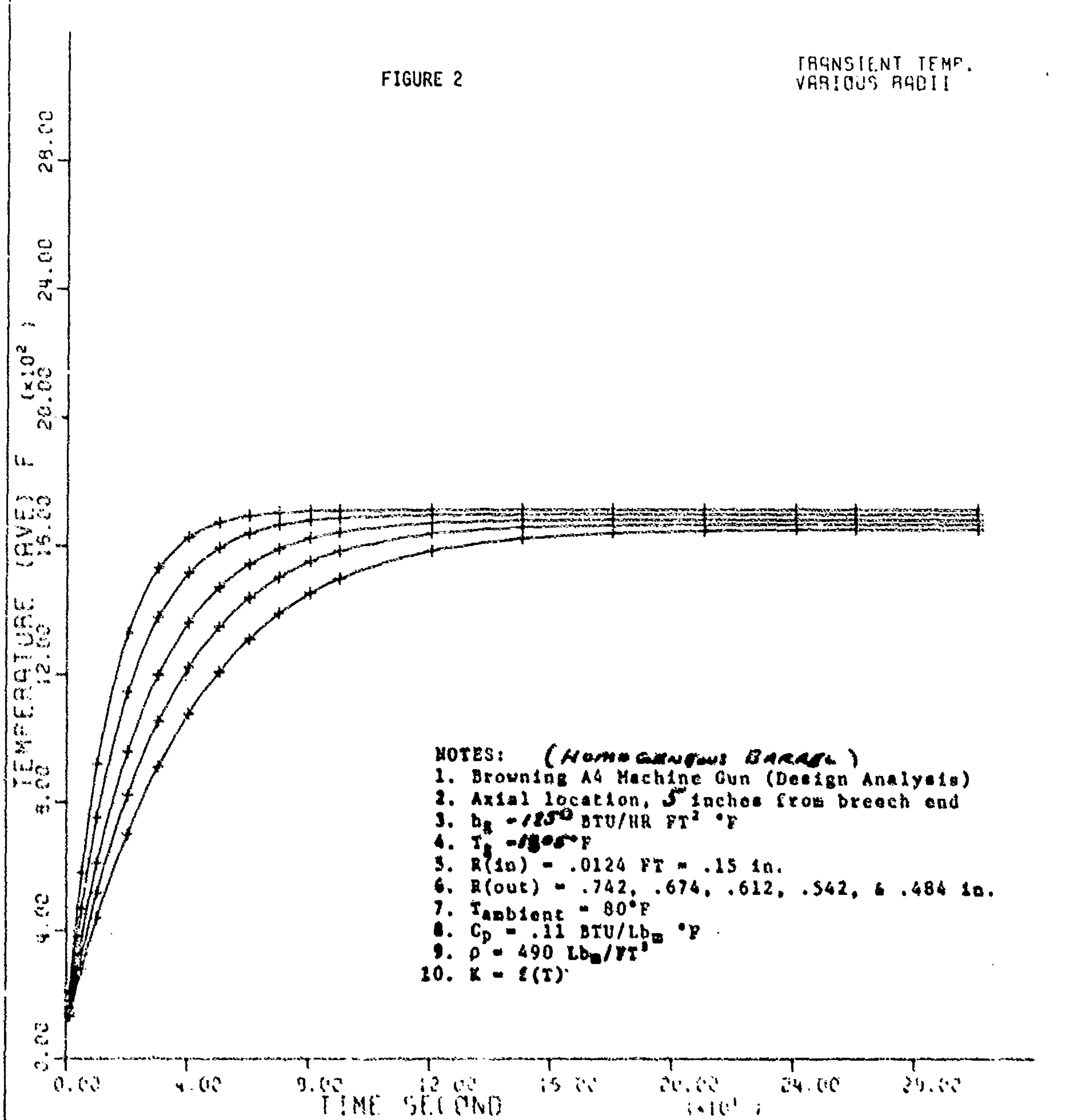
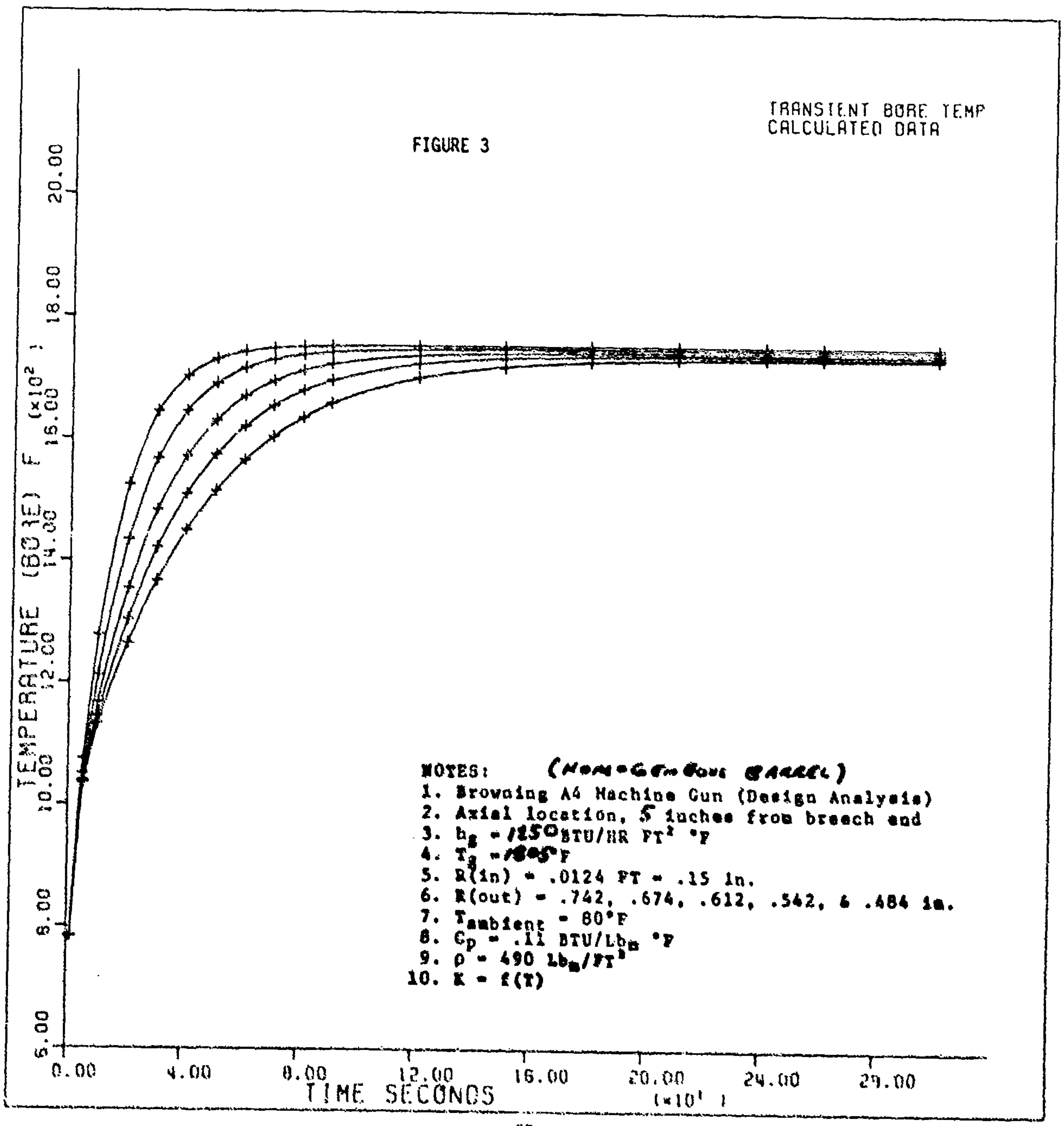


FIGURE 2
TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECOND (x10¹)
NOTES: (Homogeneous Barrel)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = BTU/HR FT² °F
4. $T_g$ = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. $C_p$ = .11 BTU/$Lb_m$ °F
9. ρ = 490 $Lb_m$/FT³
10. K = f(T)



TRANSIENT BORE TEMP
CALCULATED DATA
TEMPERATURE (BORE) F (×10²)
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TIME SECONDS (×10¹)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
NOTES: (HOMOGENEOUS BARREL)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = 1250 BTU/HR FT² °F
4. $T_g$ = 1805°F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. $C_p$ = .11 BTU/$Lb_m$ °F
9. ρ = 490 $Lb_m$/FT³
10. K = f(T)


FIGURE 3

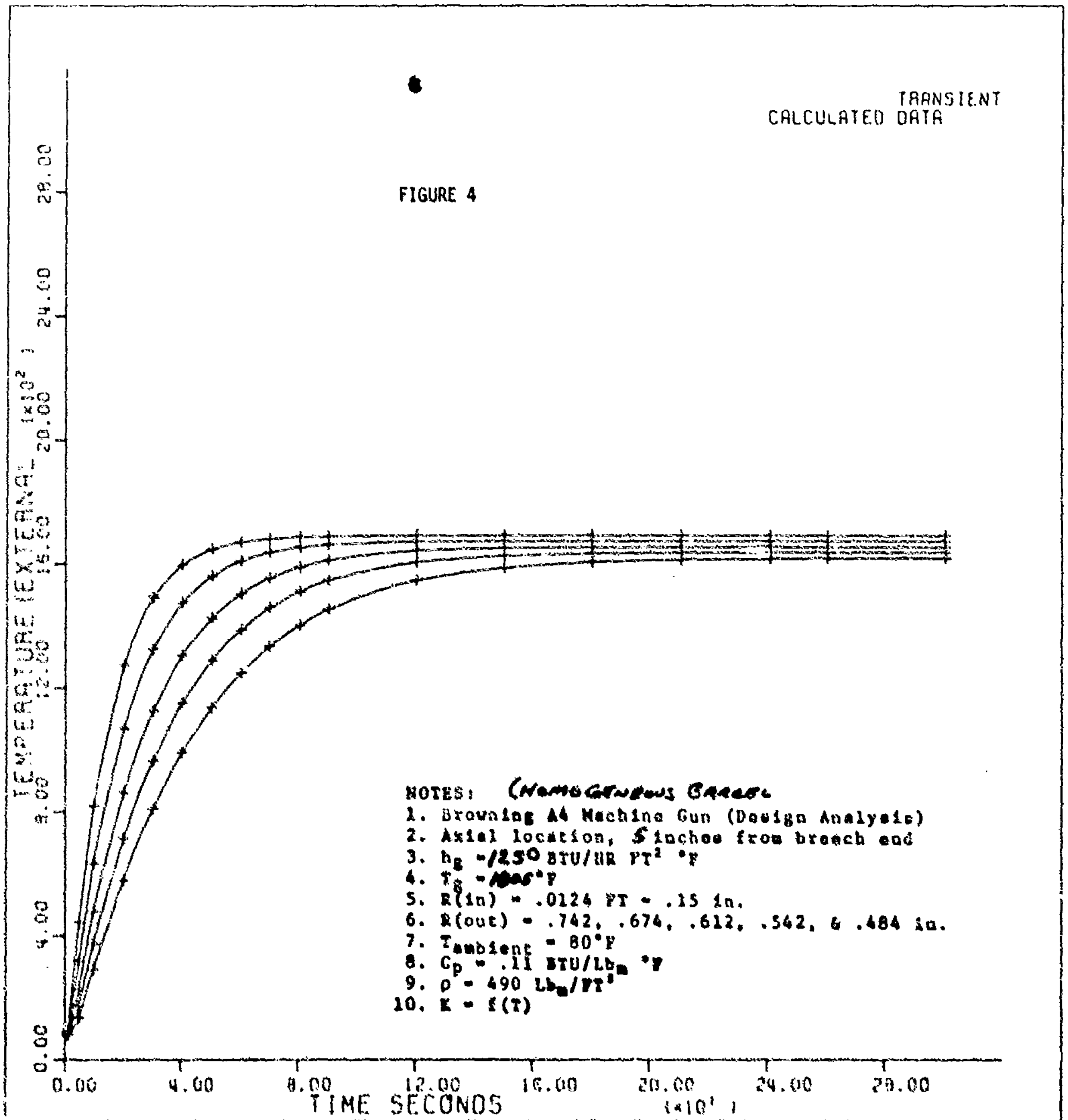
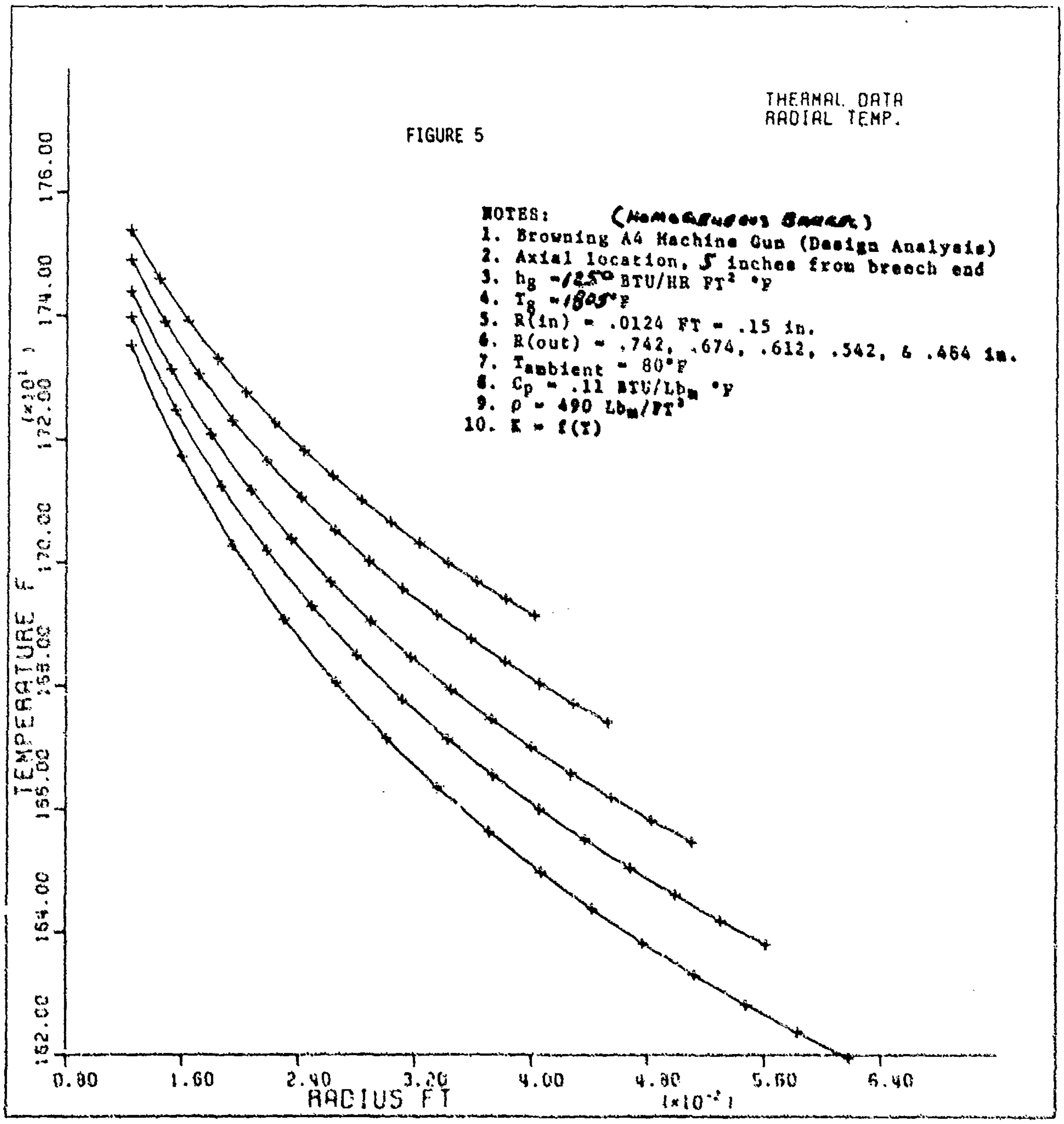

TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL) (×10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECONDS (×10¹)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
NOTES: (HOMOGENEOUS BARREL
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = 1250 BTU/HR FT² °F
4. $T_g$ = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. $C_p$ = .11 BTU/$Lb_m$ °F
9. ρ = 490 $Lb_m$/FT³
10. K = f(T)

FIGURE 4


THERMAL DATA
RADIAL TEMP.
FIGURE 5
NOTES: (Homogeneous Barrel)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = 1250 BTU/HR FT² °F
4. $T_g$ = 1805°F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .464 in.
7. $T_{ambient}$ = 80°F
8. $C_p$ = .11 BTU/Lbm °F
9. ρ = 490 Lbm/FT³
10. K = f(T)
TEMPERATURE F (×10¹)
176.00
174.00
172.00
170.00
168.00
166.00
164.00
162.00
RADIUS FT (×10⁻²)
0.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40

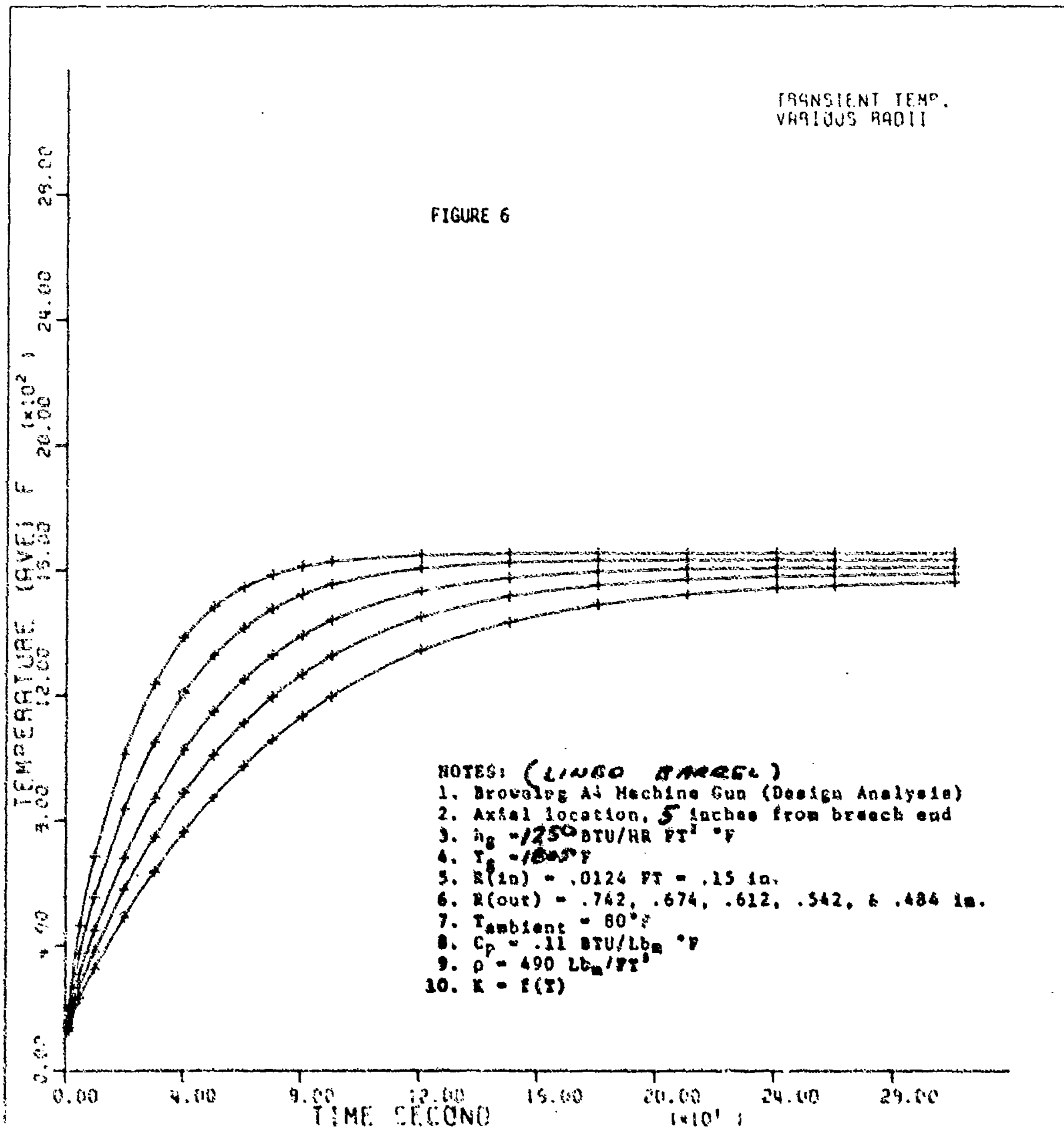
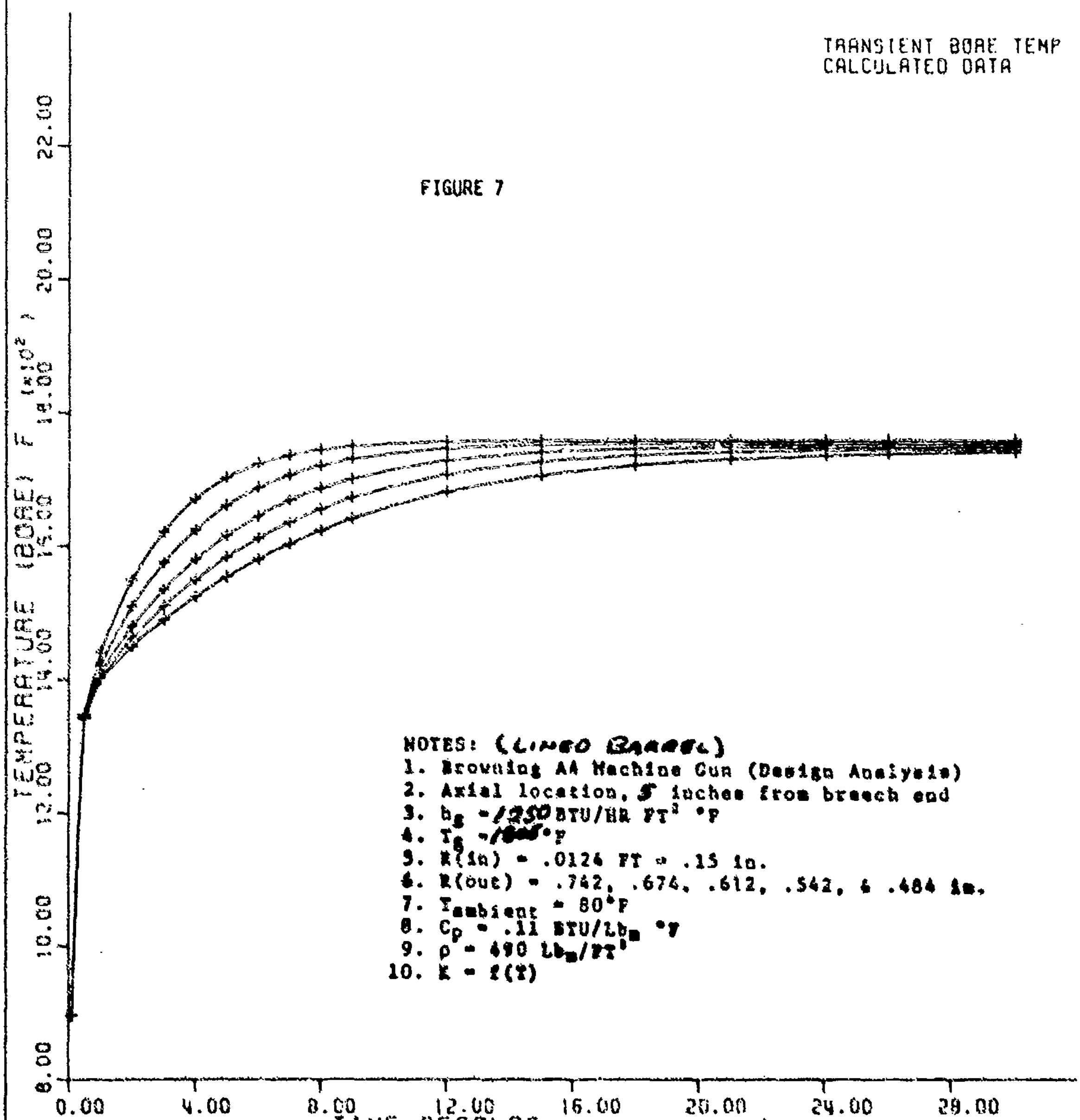
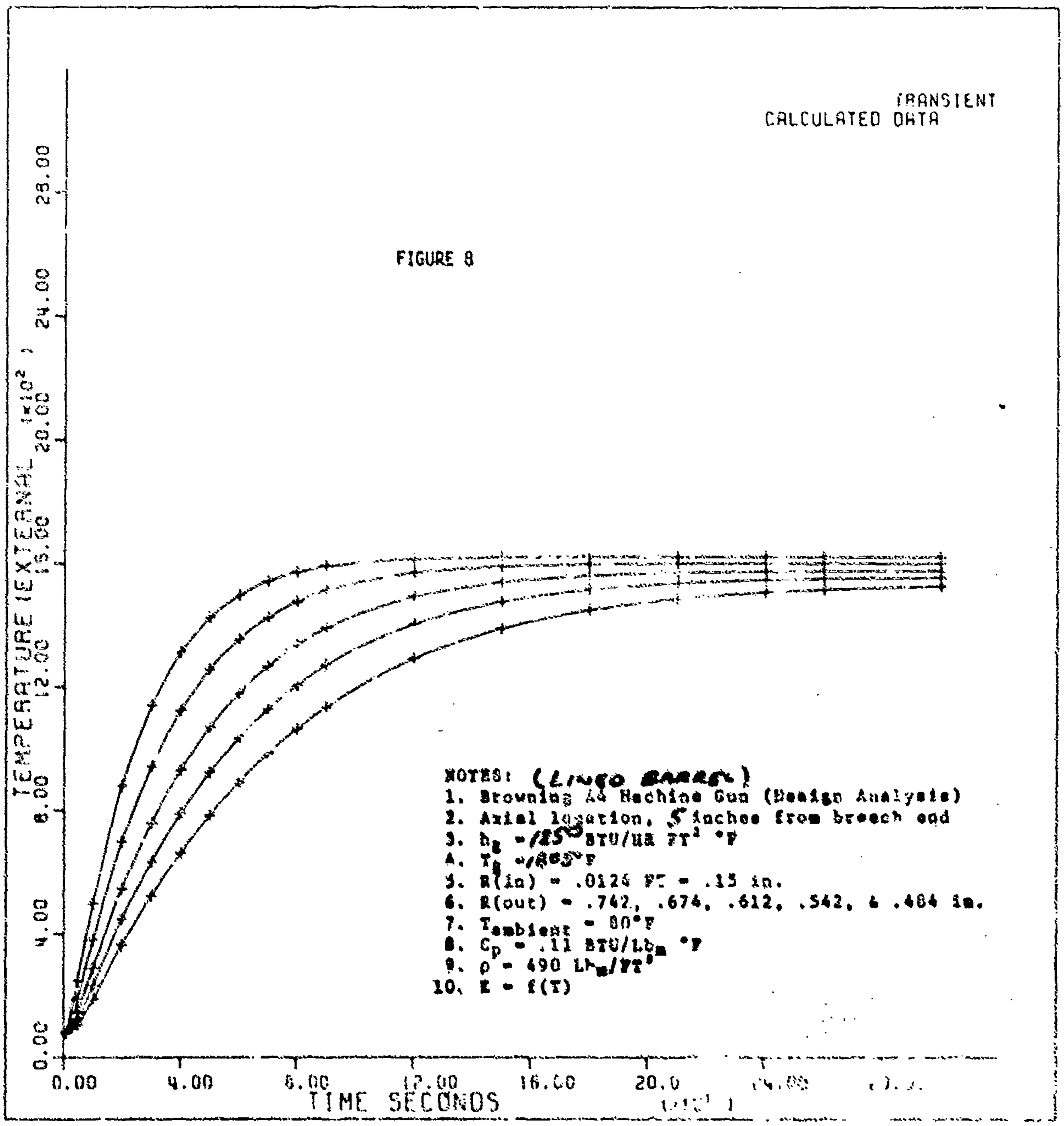

TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (×10²)
TIME SECOND (×10¹)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
NOTES: (LINGO BARREL)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = 1250 BTU/HR FT² °F
4. $T_g$ = 1800 °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80 °F
8. $C_p$ = .11 BTU/$Lb_m$ °F
9. ρ = 490 $Lb_m$/FT³
10. K = f(T)

FIGURE 6



TRANSIENT BORE TEMP
CALCULATED DATA
TEMPERATURE (BORE) F (×10²)
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
TIME SECONDS (×10¹)
NOTES: (LINED BARREL)
1. Browning AA Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = 1250 BTU/HR FT² °F
4. $T_g$ = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. $T_{ambient}$ = 80°F
8. $C_p$ = .11 BTU/$Lb_m$ °F
9. ρ = 490 $Lb_m/FT^3$
10. K = f(T)


FIGURE 7


TRANSIENT
CALCULATED DATA
FIGURE 8
TEMPERATURE (EXTERNAL (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
0.00
4.00
8.00
12.00
16.00
20.0
TIME SECONDS
NOTES:
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. h_g = BTU/HR FT² °F
A. T_g = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .484 in.
7. T_ambient = 80°F
8. C_p = .11 BTU/Lb_m °F
9. ρ = 490 Lb_m/FT³
10. E = f(T)

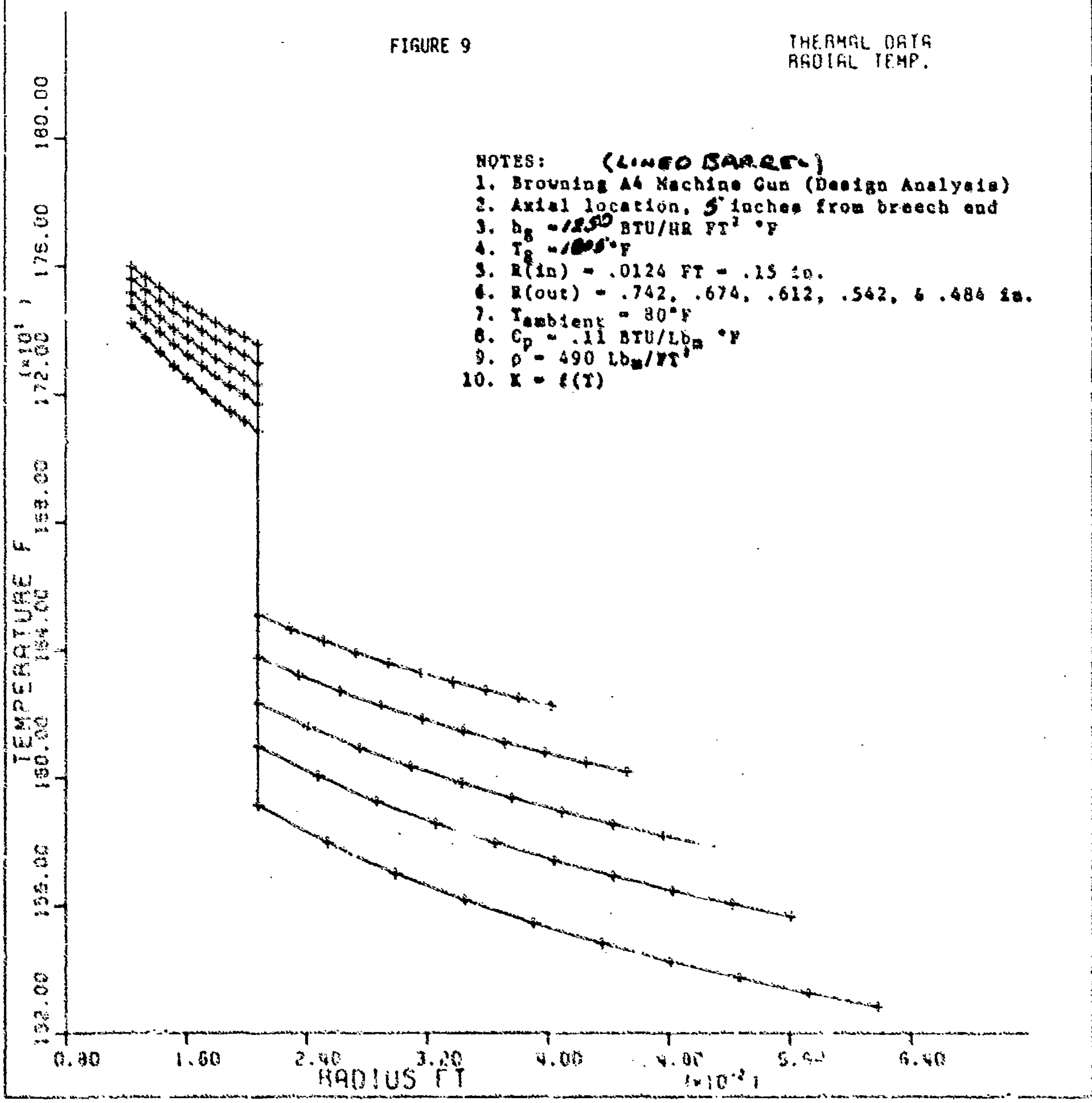


FIGURE 9
THERMAL DATA
RADIAL TEMP.
NOTES: (LINED BARREL)
1. Browning A4 Machine Gun (Design Analysis)
2. Axial location, 5 inches from breech end
3. $h_g$ = 1250 BTU/HR FT² °F
4. $T_g$ = °F
5. R(in) = .0124 FT = .15 in.
6. R(out) = .742, .674, .612, .542, & .486 in.
7. $T_{ambient}$ = 80°F
8. $C_p$ = .11 BTU/$Lb_m$ °F
9. ρ = 490 $Lb_m$/FT³
10. K = f(T)
TEMPERATURE F (×10¹)
180.00
176.00
172.00
168.00
164.00
160.00
156.00
152.00
RADIUS FT (×10⁻²)
0.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40

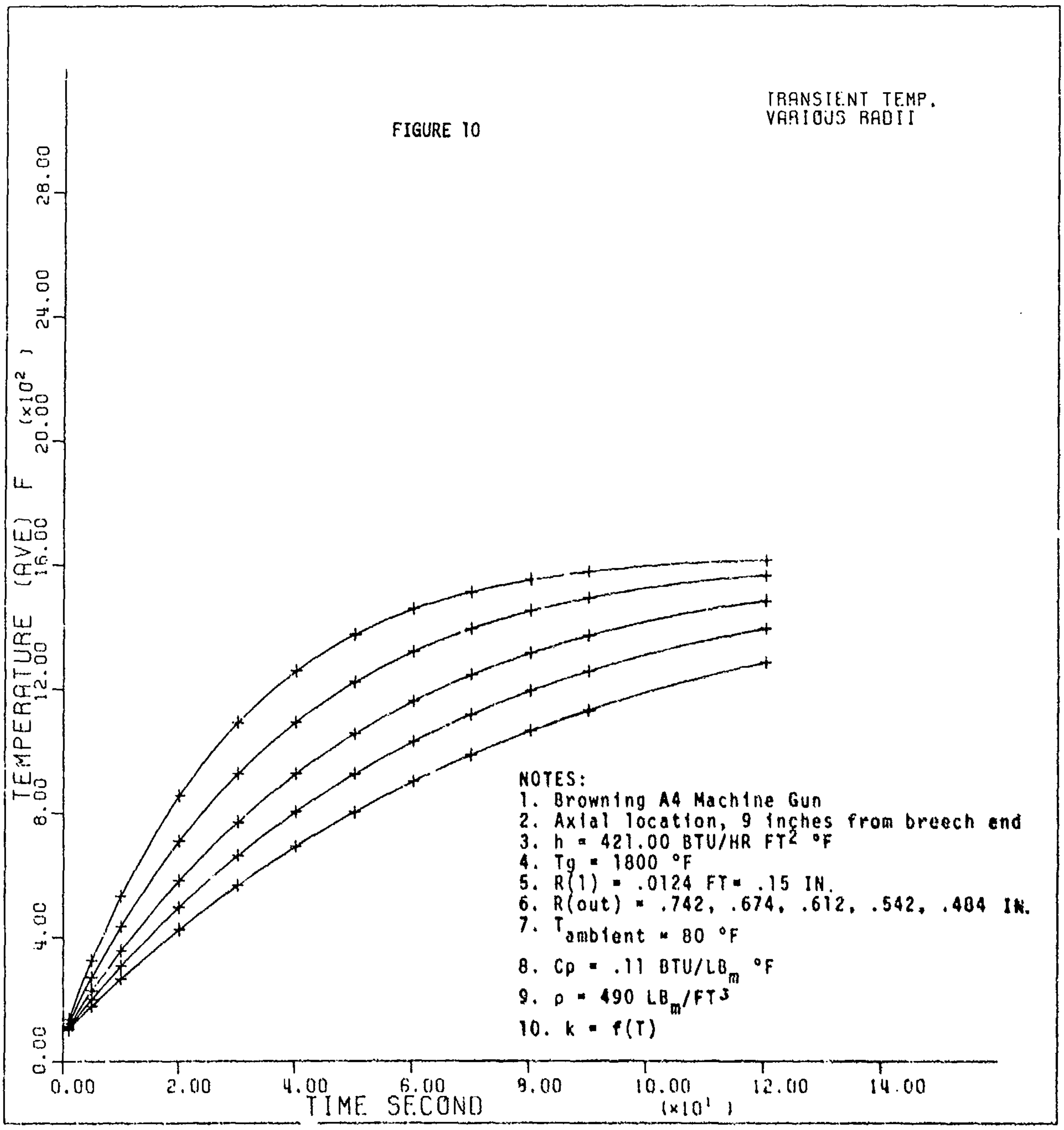


FIGURE 10
TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
TIME SECOND (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
20.00
24.00
28.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

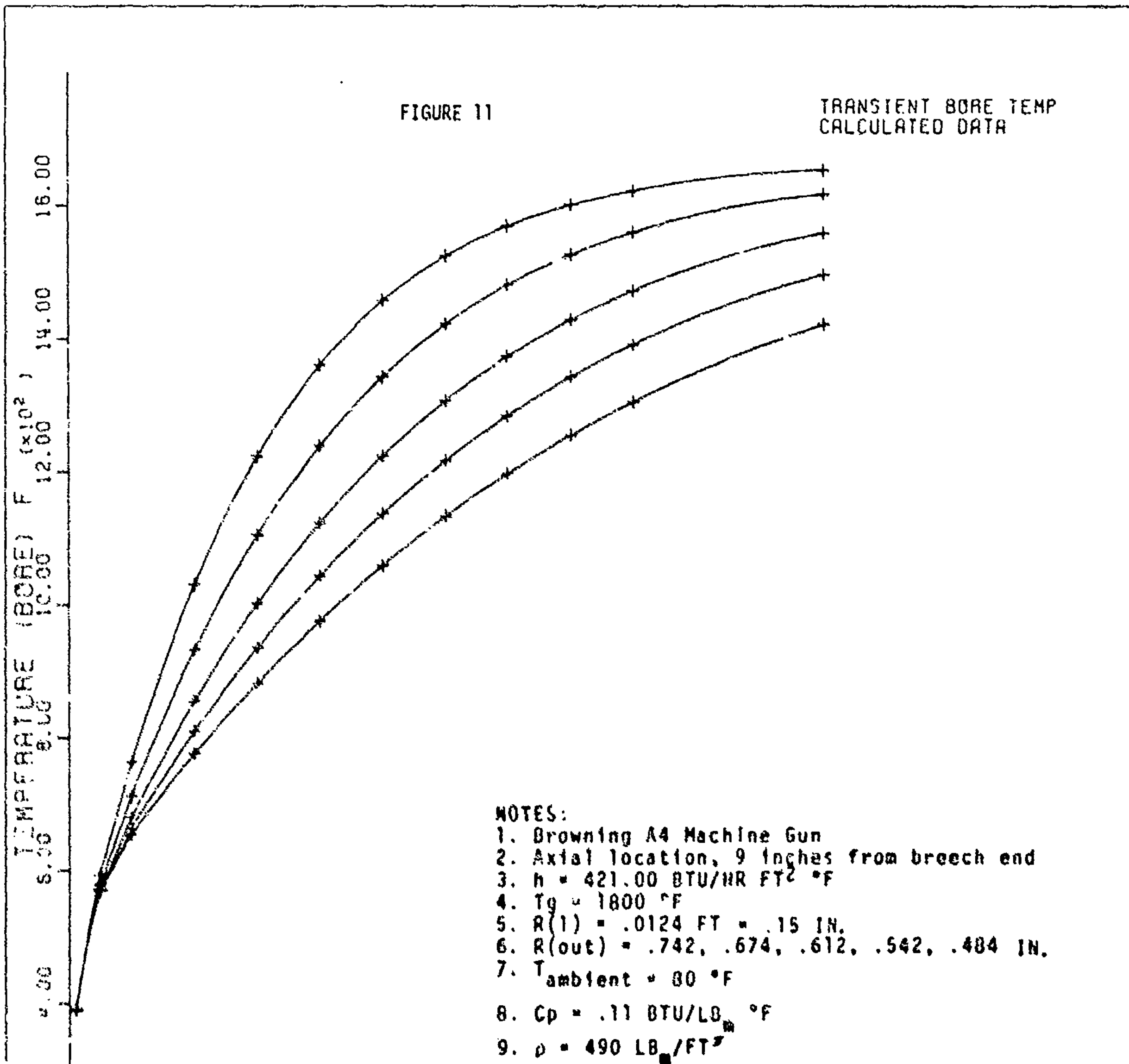
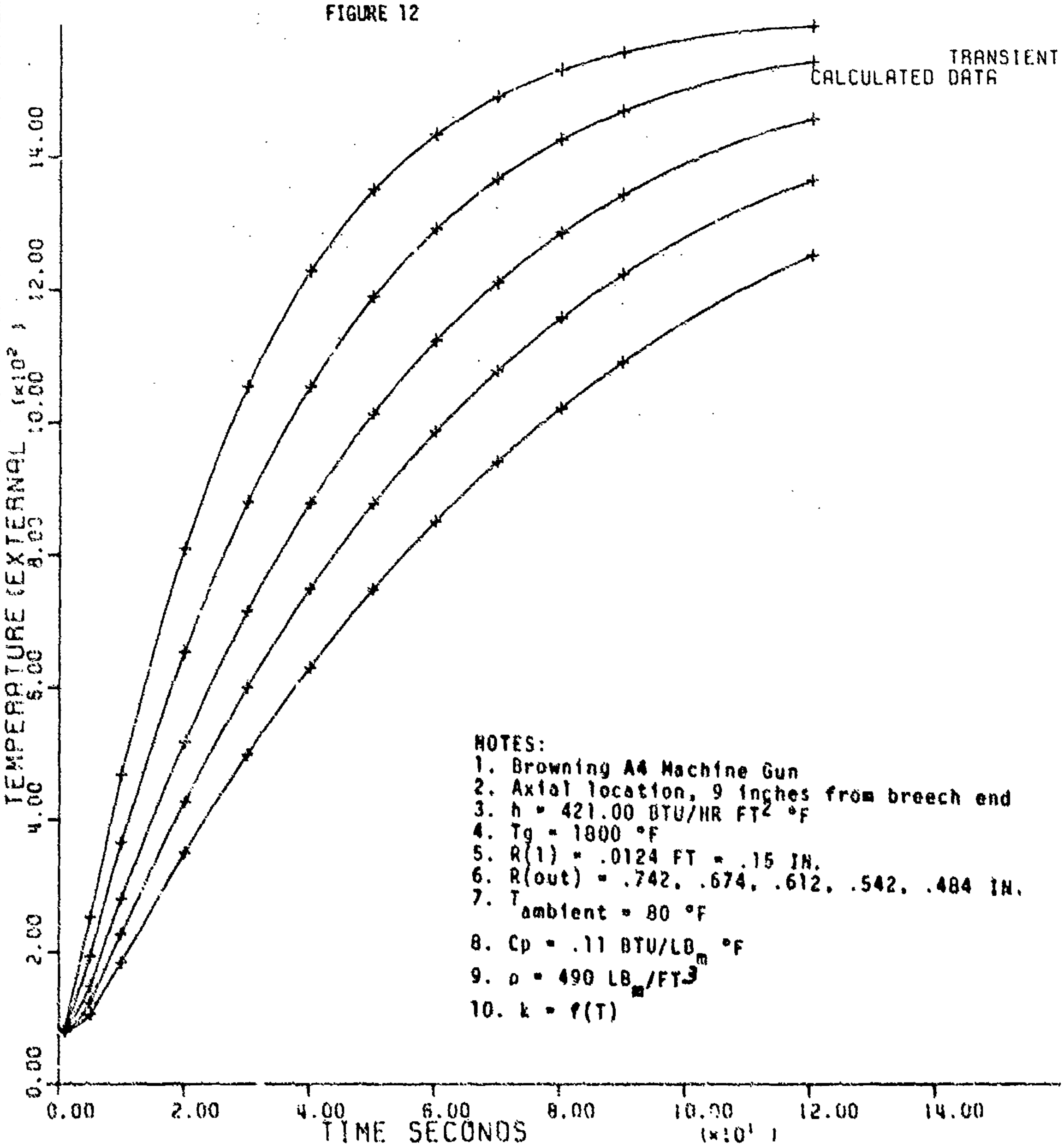


FIGURE 11
TRANSIENT BORE TEMP
CALCULATED DATA
TEMPERATURE (BORE) F (x10²)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS (x10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

FIGURE 12



TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL (×10²)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS (×10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT3
10. k = f(T)

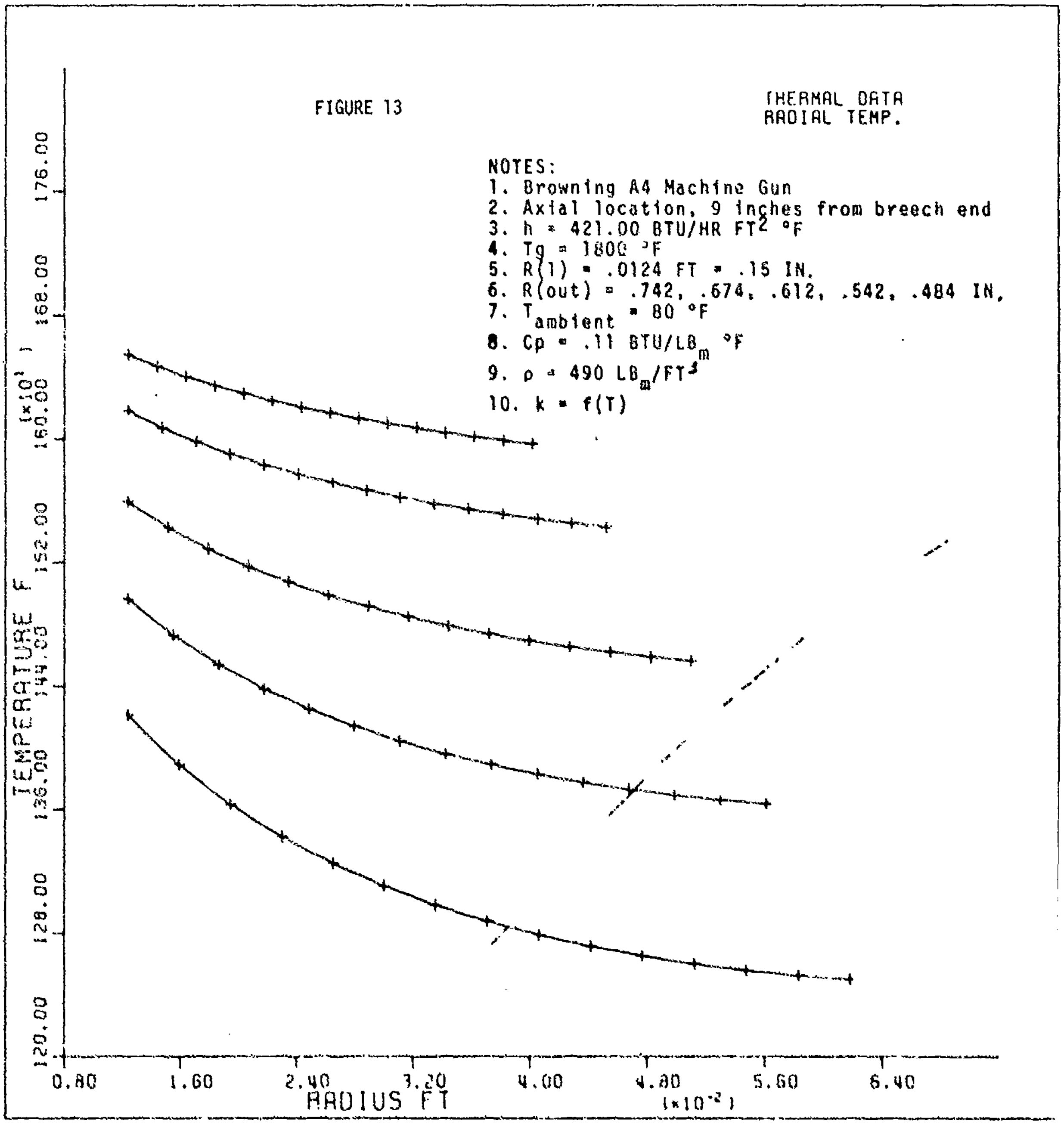
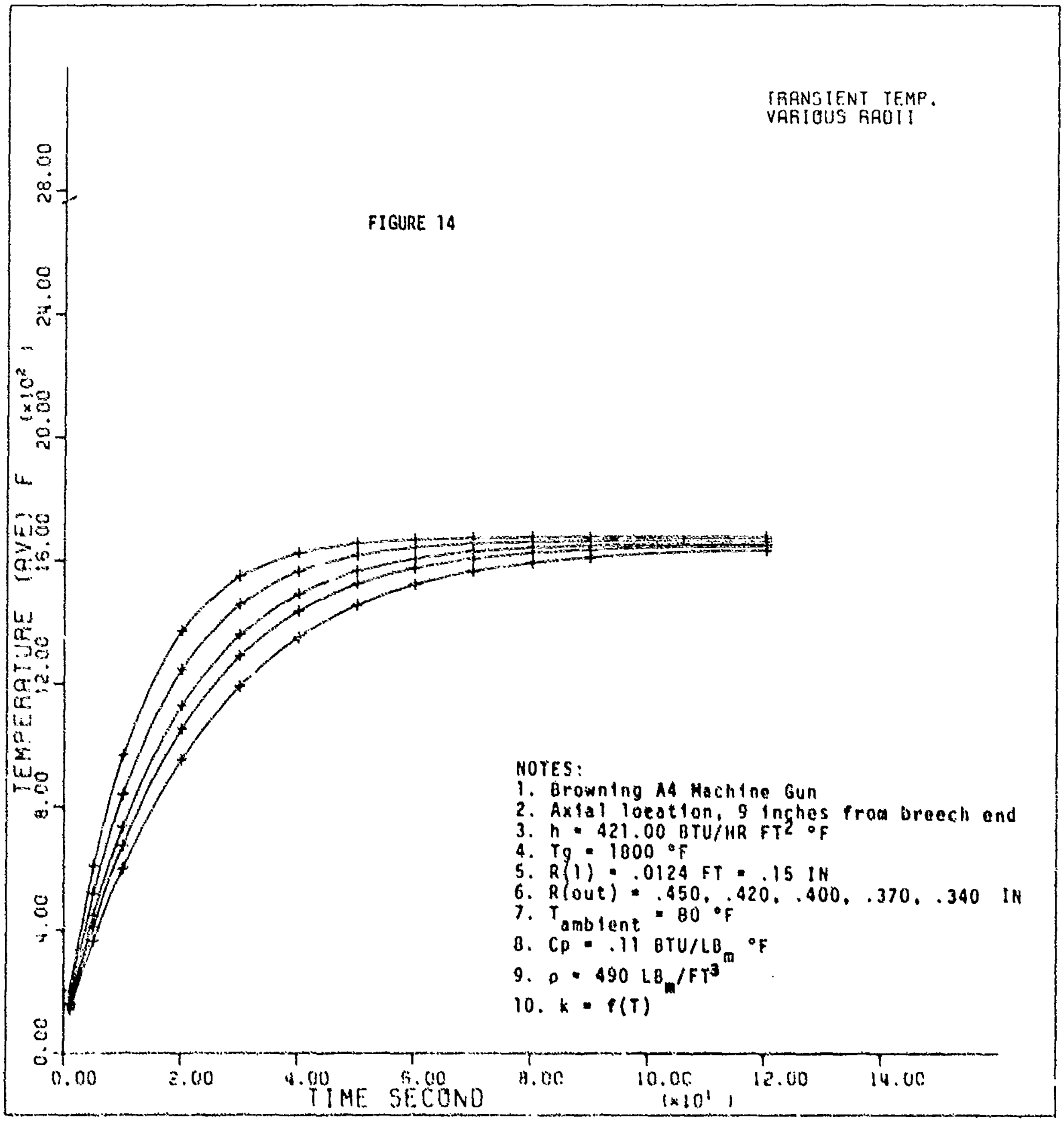
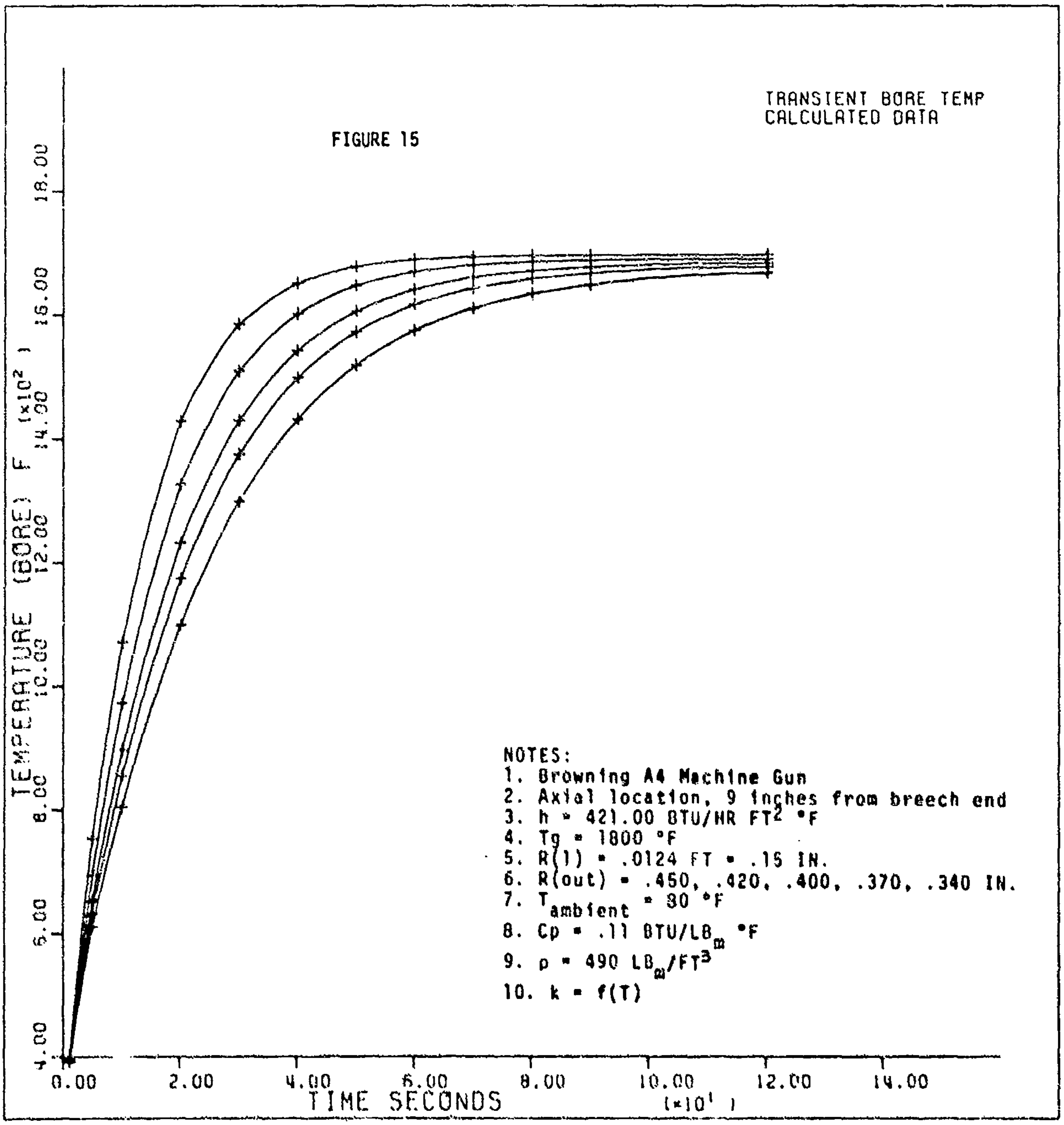


FIGURE 13
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .742, .674, .612, .542, .484 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)
TEMPERATURE F (x10¹)
176.00
168.00
160.00
152.00
144.00
136.00
128.00
120.00
RADIUS FT (x10⁻²)
0.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40



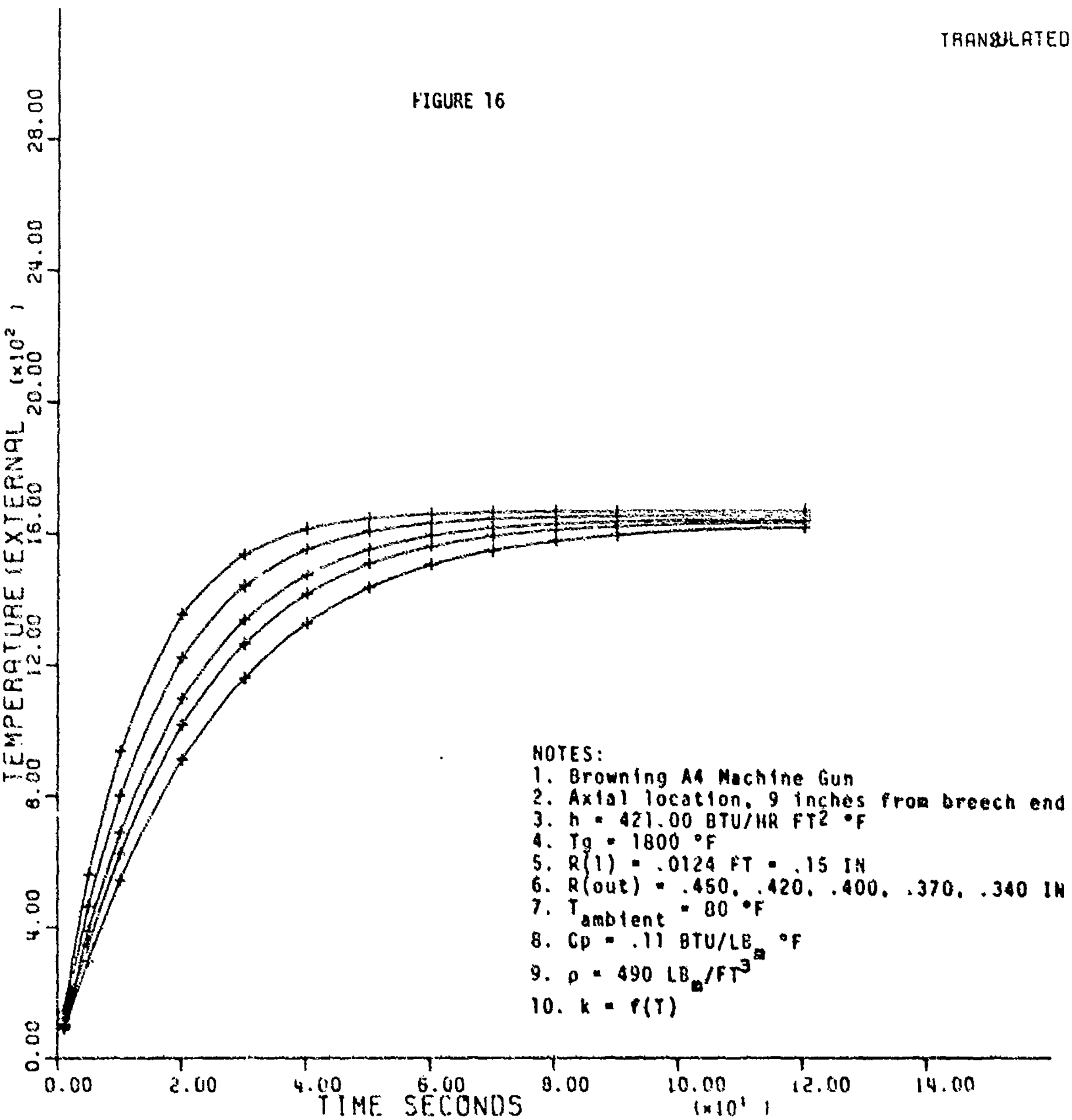
TRANSIENT TEMP.
VARIOUS RADII
FIGURE 14
TEMPERATURE (AVE) F (x10²)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN
6. R(out) = .450, .420, .400, .370, .340 IN
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECOND
(x10¹)

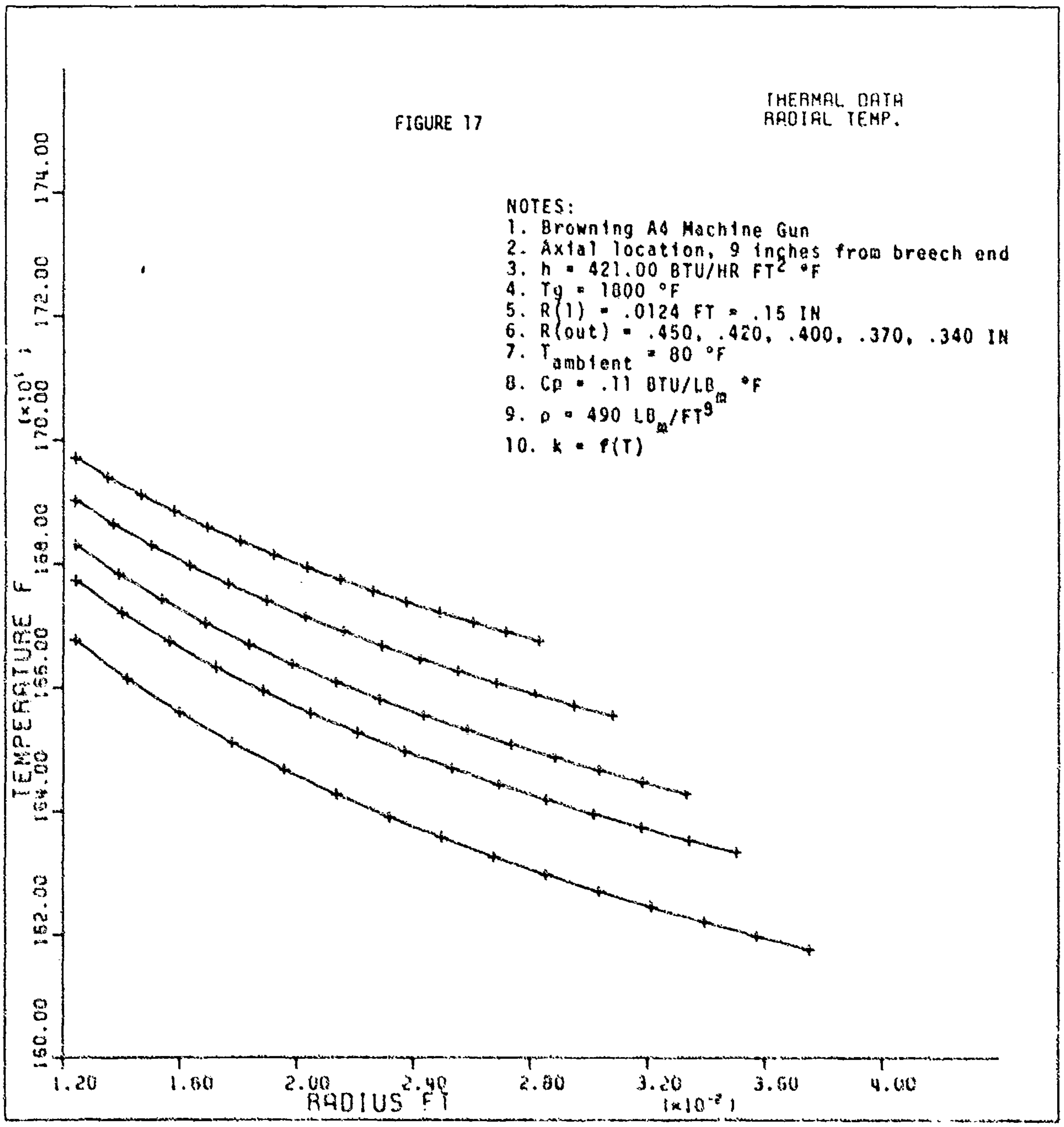


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 15
TEMPERATURE (BORE) F (×10²)
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS (×10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)

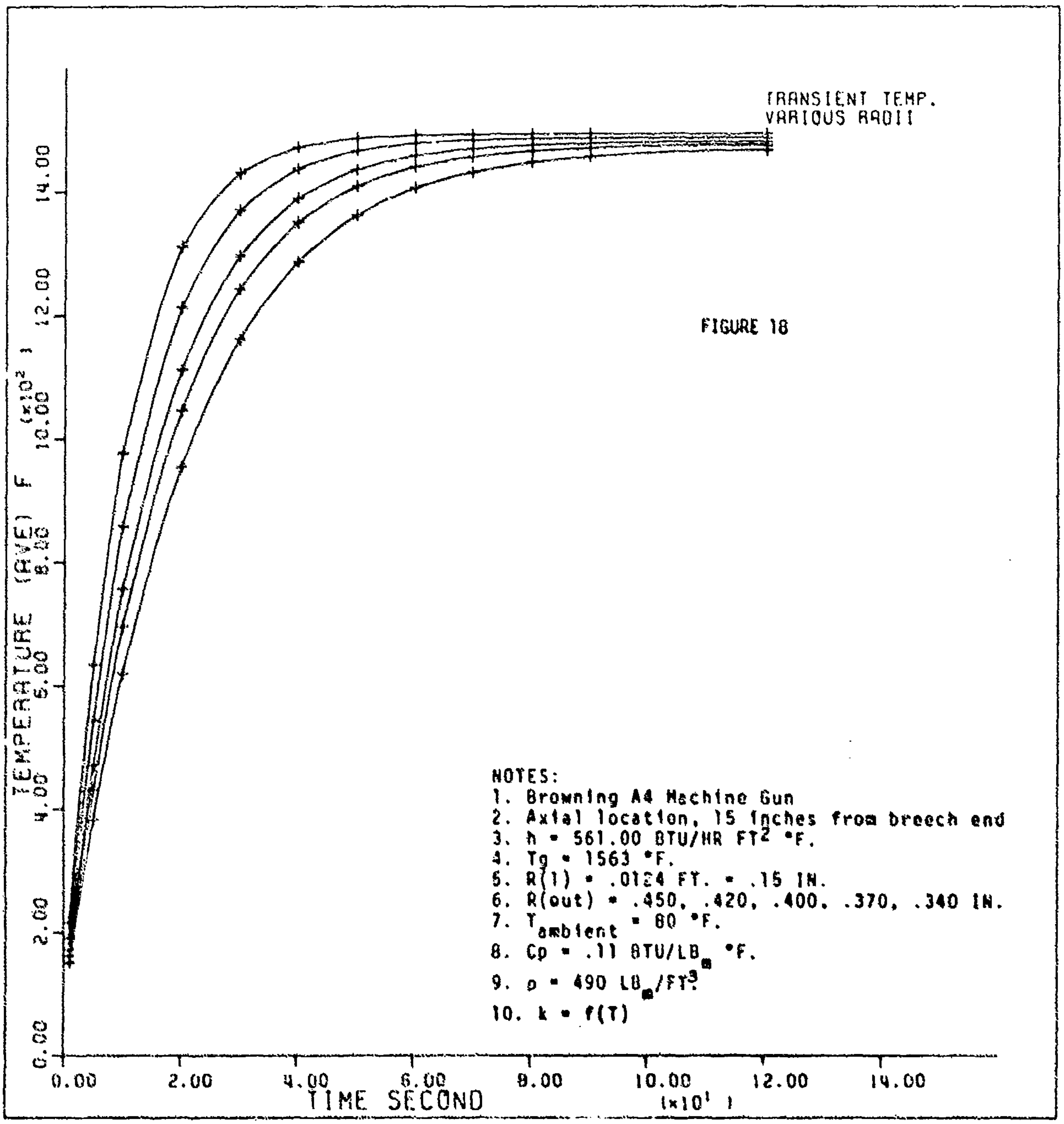
TRANSULATED DATA

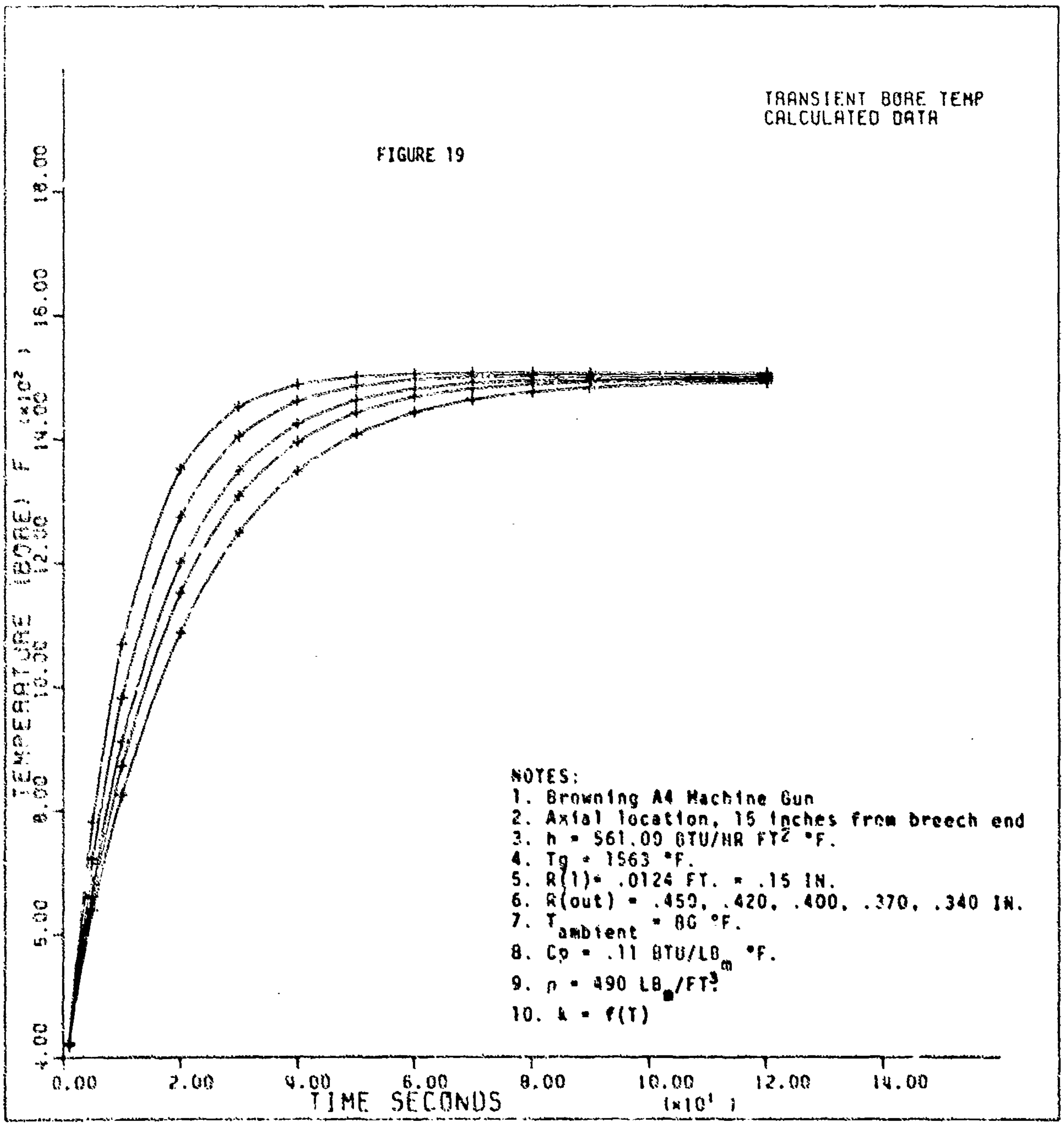
FIGURE 16

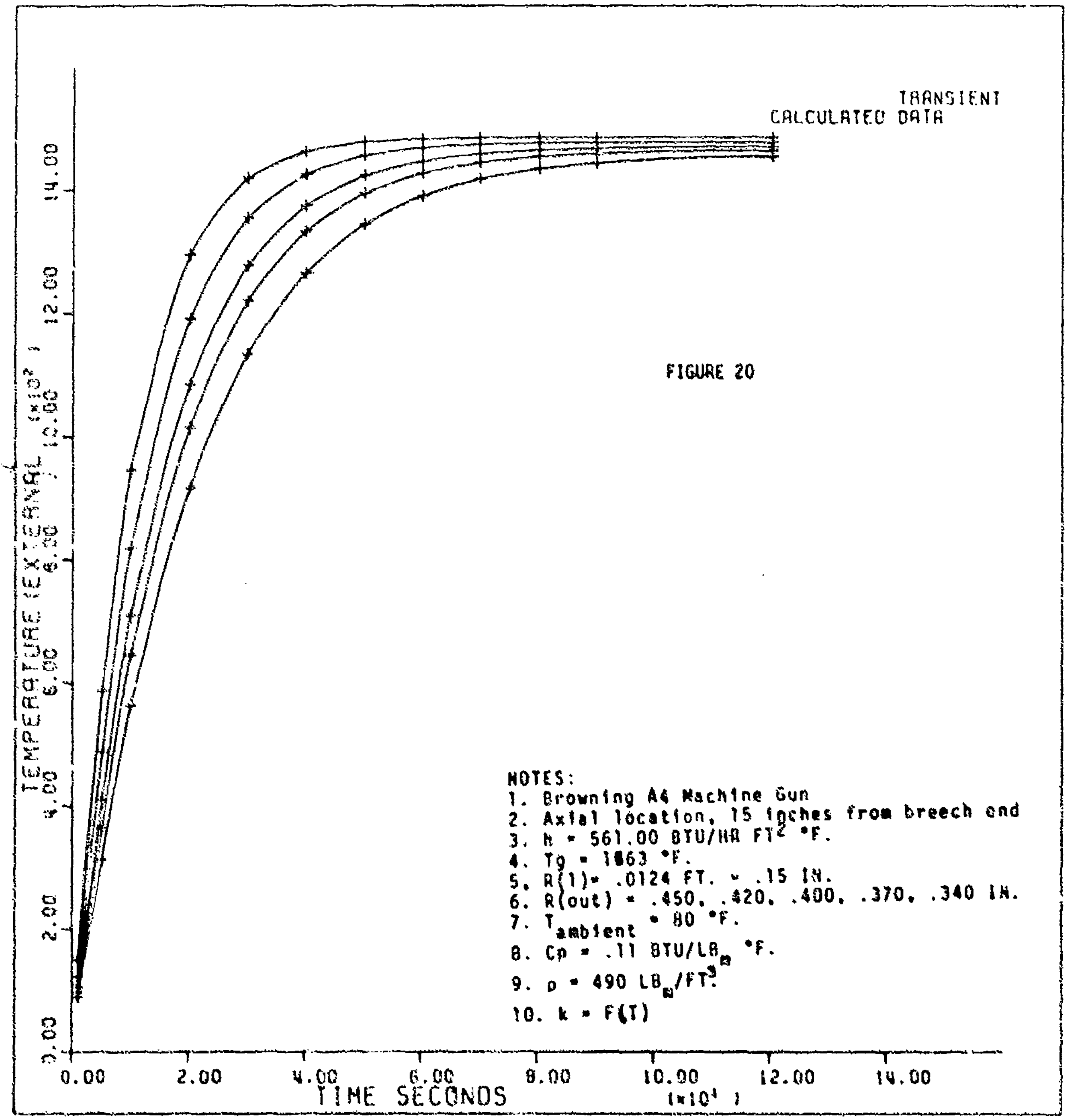




THERMAL DATA
RADIAL TEMP.
FIGURE 17
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 9 inches from breech end
3. h = 421.00 BTU/HR FT² °F
4. Tg = 1800 °F
5. R(1) = .0124 FT = .15 IN
6. R(out) = .450, .420, .400, .370, .340 IN
7. T ambient = 80 °F
8. Cp = .11 BTU/LBm °F
9. ρ = 490 LBm/FT³
10. k = f(T)
TEMPERATURE F (×10¹)
160.00
162.00
164.00
166.00
168.00
170.00
172.00
174.00
RADIUS FT (×10⁻²)
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00


TRANSIENT TEMP.
VARIOUS RADII
FIGURE 18
TEMPERATURE (AVE) F (x10² )
TIME SECOND (x10¹ )
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³.
10. k = f(T)


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 19
TEMPERATURE (BORE) F (x10²)
TIME SECONDS (x10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)


TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL) (x10² )
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS (x10¹ )
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT² °F.
4. Tg = 1863 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = F(T)
FIGURE 20

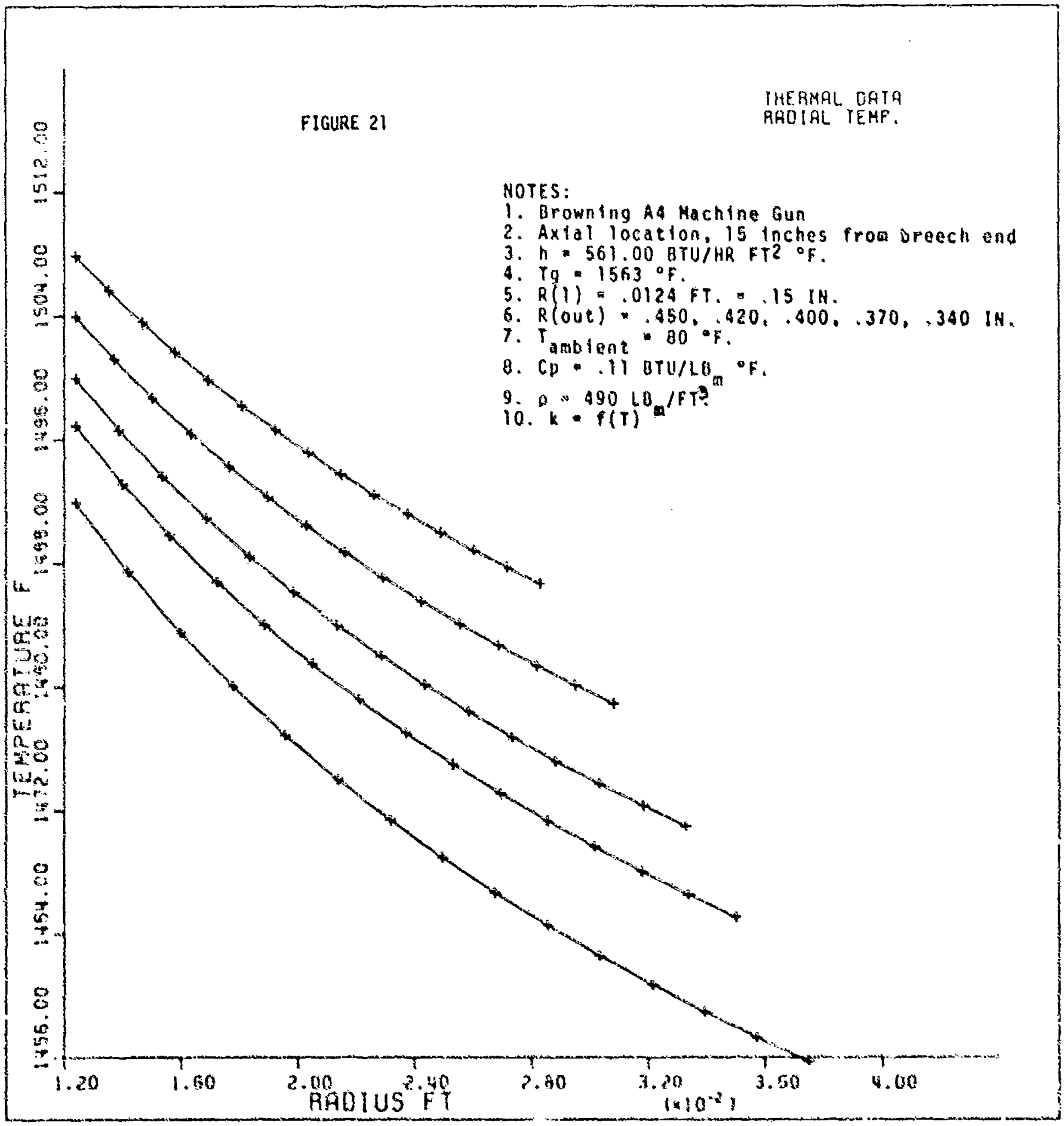
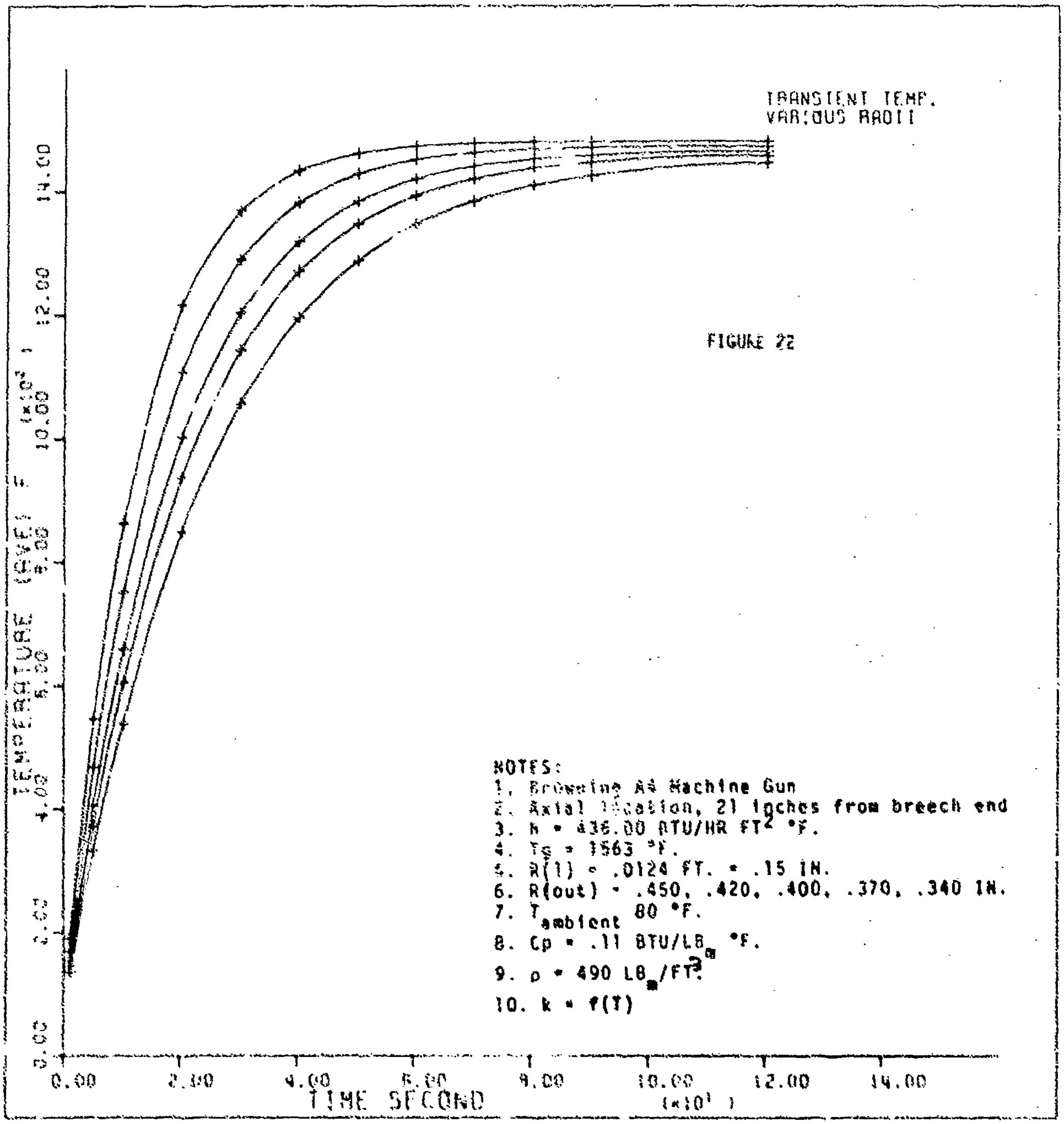
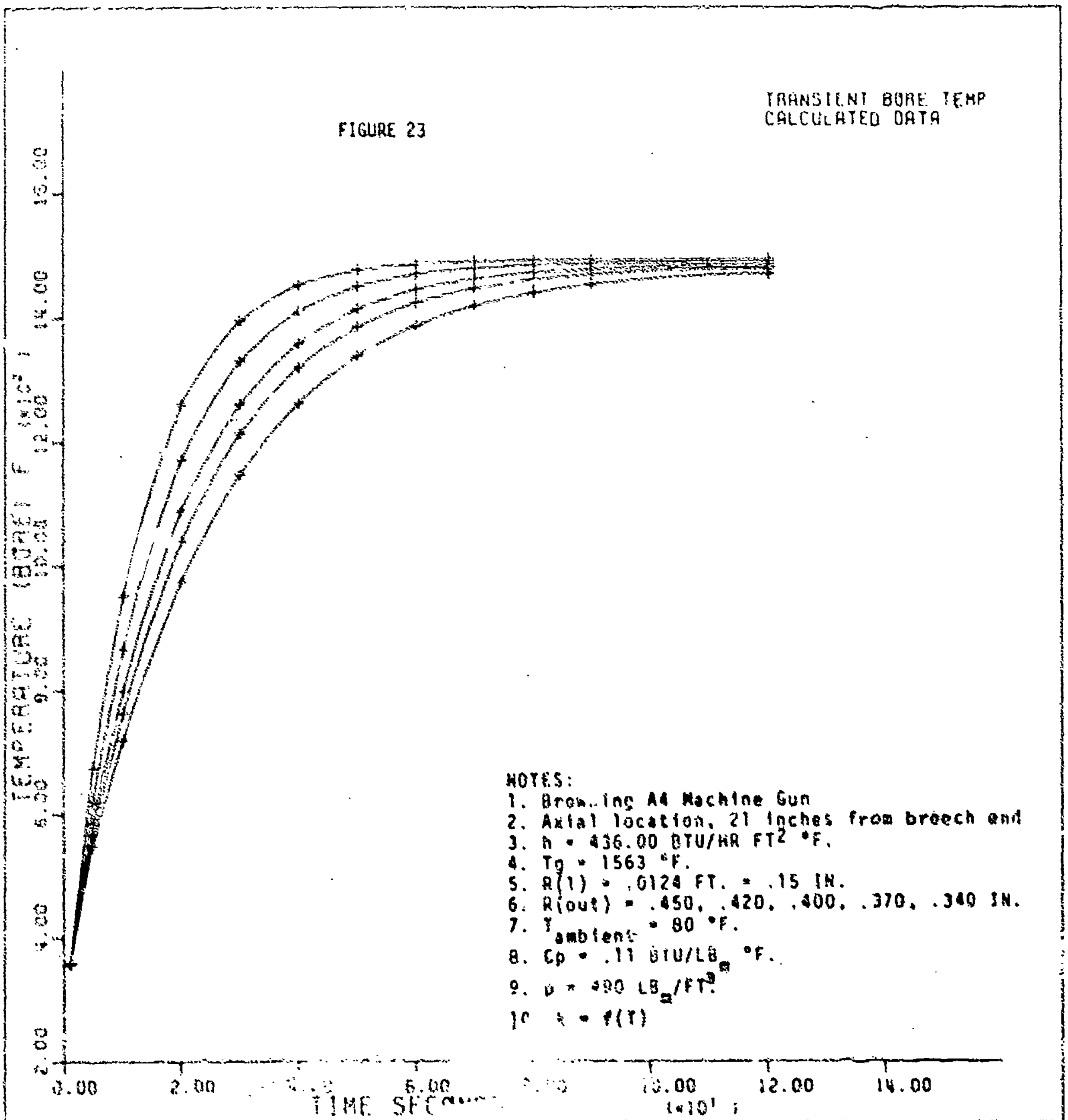


FIGURE 21
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 15 inches from breech end
3. h = 561.00 BTU/HR FT2 °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .460, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT3
10. k = f(T)
TEMPERATURE F
1512.00
1504.00
1496.00
1488.00
1480.00
1472.00
1464.00
1456.00
RADIUS FT
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
(x10^-2)


TRANSIENT TEMP.
VARIOUS RADII
FIGURE 22
TEMPERATURE (AVE) F. (x10² )
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECOND (x10¹ )
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 23
NOTES:
1. Brow.ing A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT2 °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT3
10. k = f(T)
0.00
2.00
6.00
10.00
12.00
14.00
4.00
16.00
14.00
12.00
TIME SEC
TEMPERATURE (BORE) F

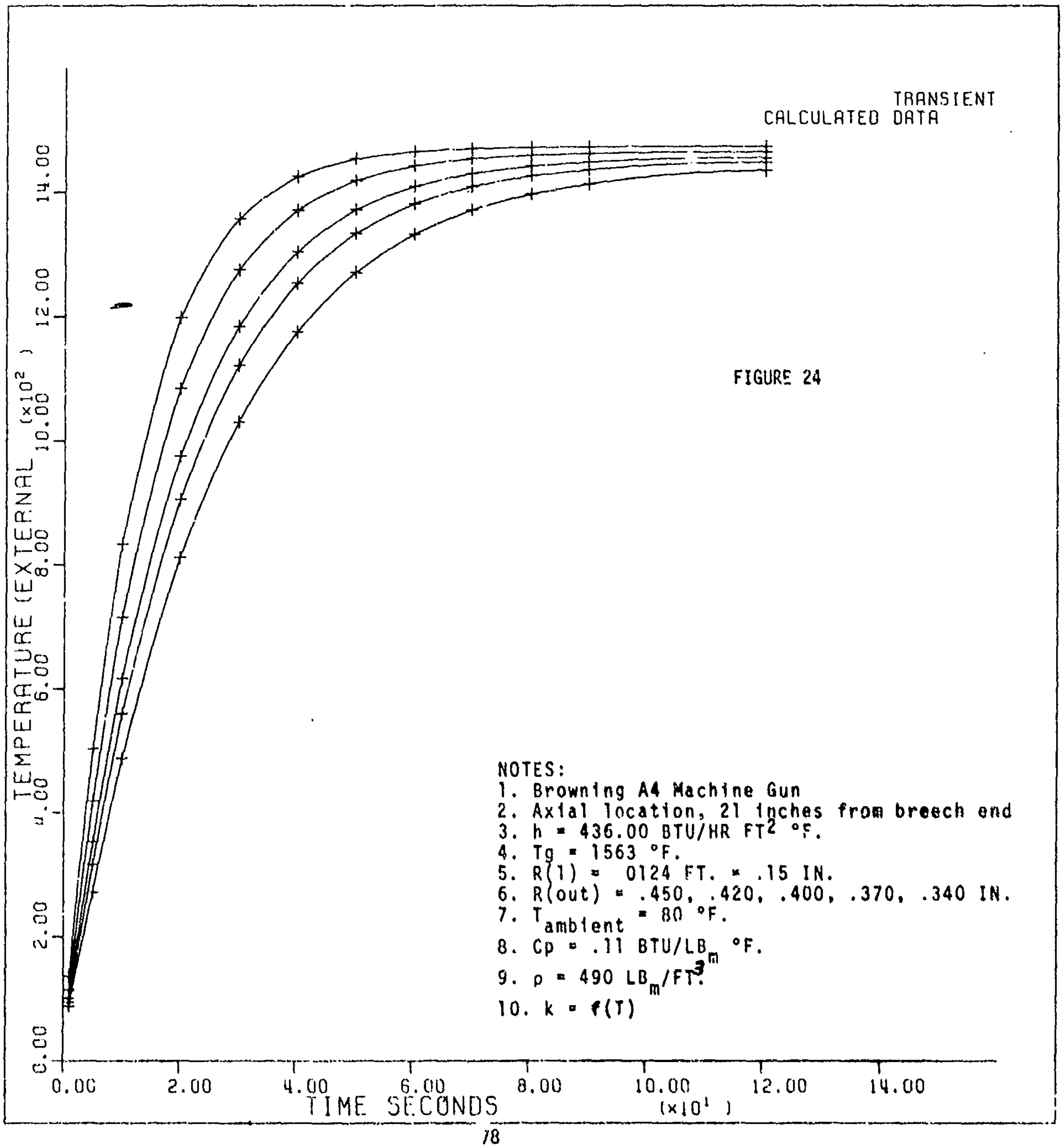

TRANSIENT
CALCULATED DATA
TEMPERATURE (EXTERNAL (x10² )
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
TIME SECONDS
(x10¹ )
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = 0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LB m °F.
9. ρ = 490 LB m/FT³
10. k = f(T)

FIGURE 24

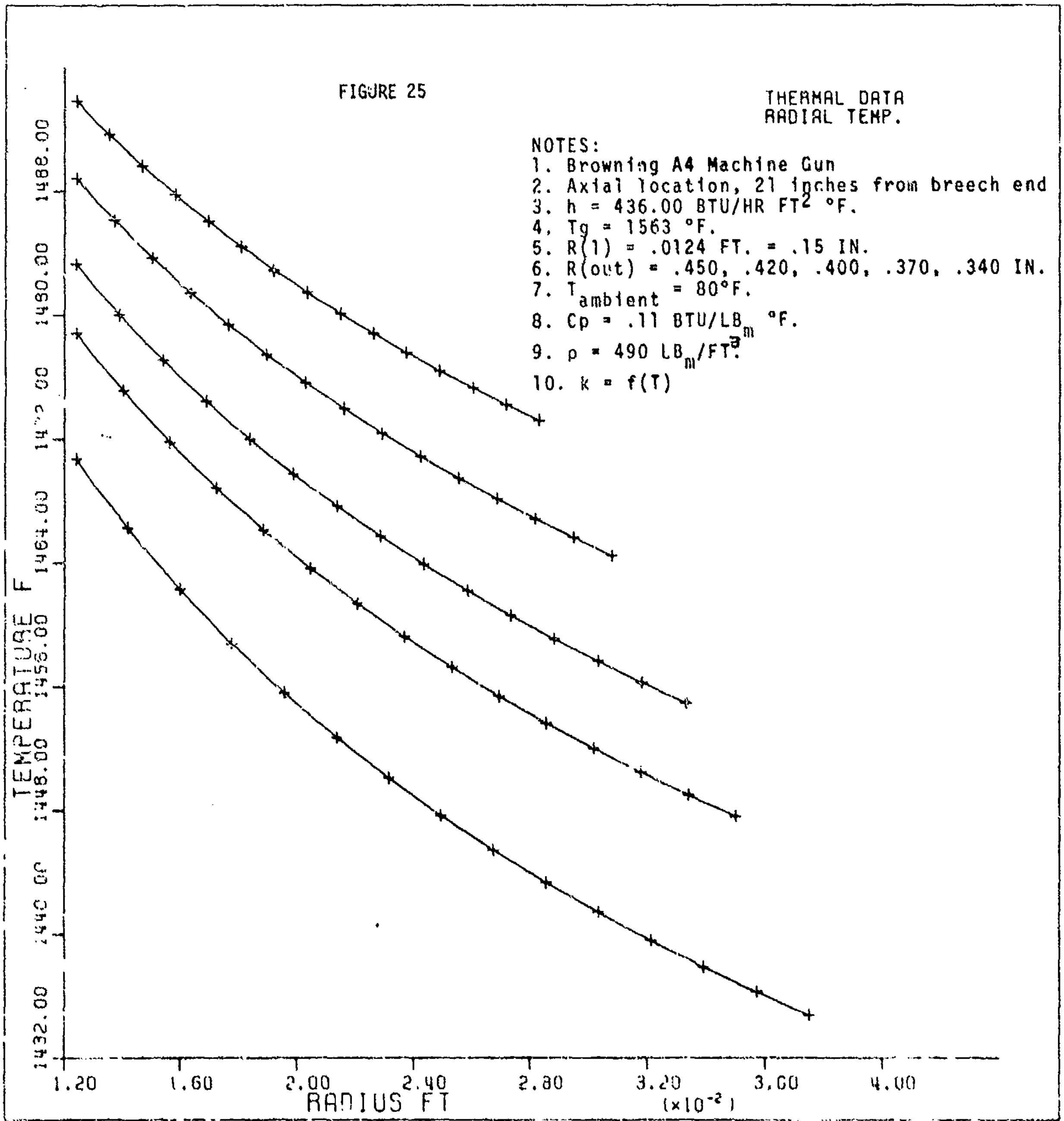


FIGURE 25
THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT$^2$ °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .450, .420, .400, .370, .340 IN.
7. $T_{ambient}$ = 80°F.
8. Cp = .11 BTU/$LB_m$ °F.
9. ρ = 490 $LB_m$/FT$^3$
10. k = f(T)
TEMPERATURE F
1432.00
1440.00
1448.00
1456.00
1464.00
1480.00
1488.00
RADIUS FT
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
(×10$^{-2}$)

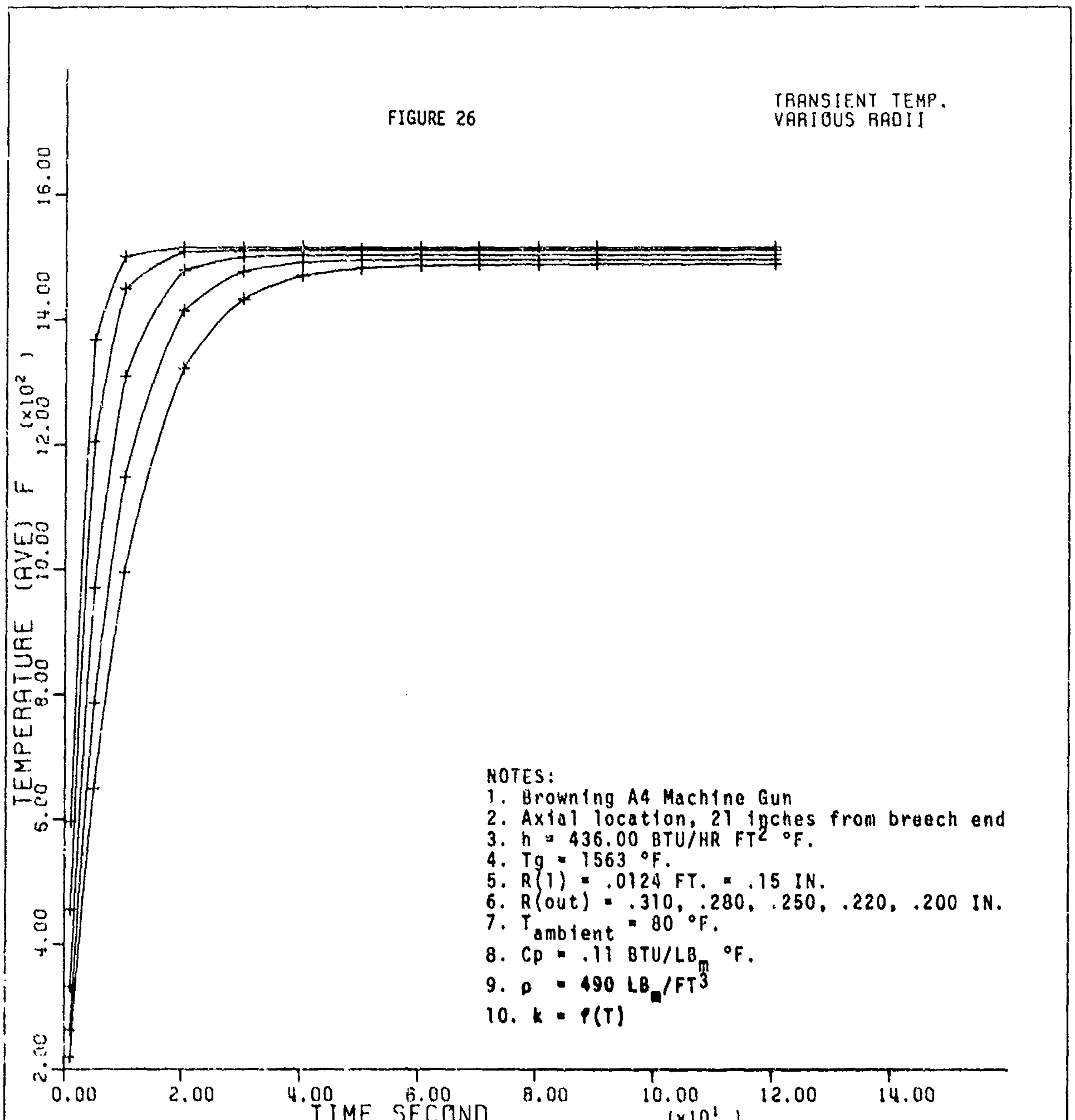
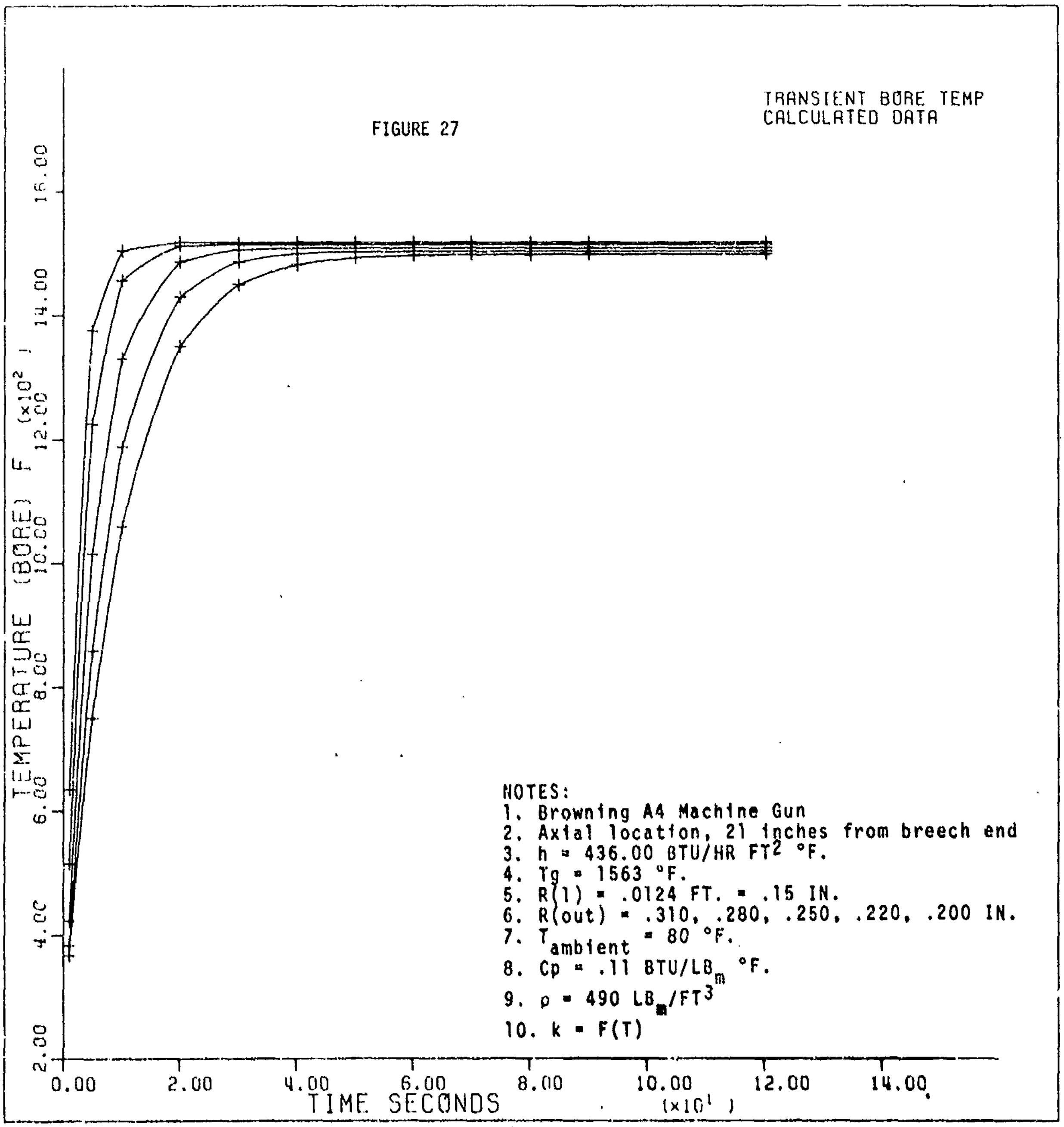


FIGURE 26
TRANSIENT TEMP.
VARIOUS RADII
TEMPERATURE (AVE) F (x10²)
TIME SECOND (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = f(T)


TRANSIENT BORE TEMP
CALCULATED DATA
FIGURE 27
TEMPERATURE (BORE) F (x10²)
TIME SECONDS (x10¹)
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT² °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. T ambient = 80 °F.
8. Cp = .11 BTU/LBm °F.
9. ρ = 490 LBm/FT³
10. k = F(T)

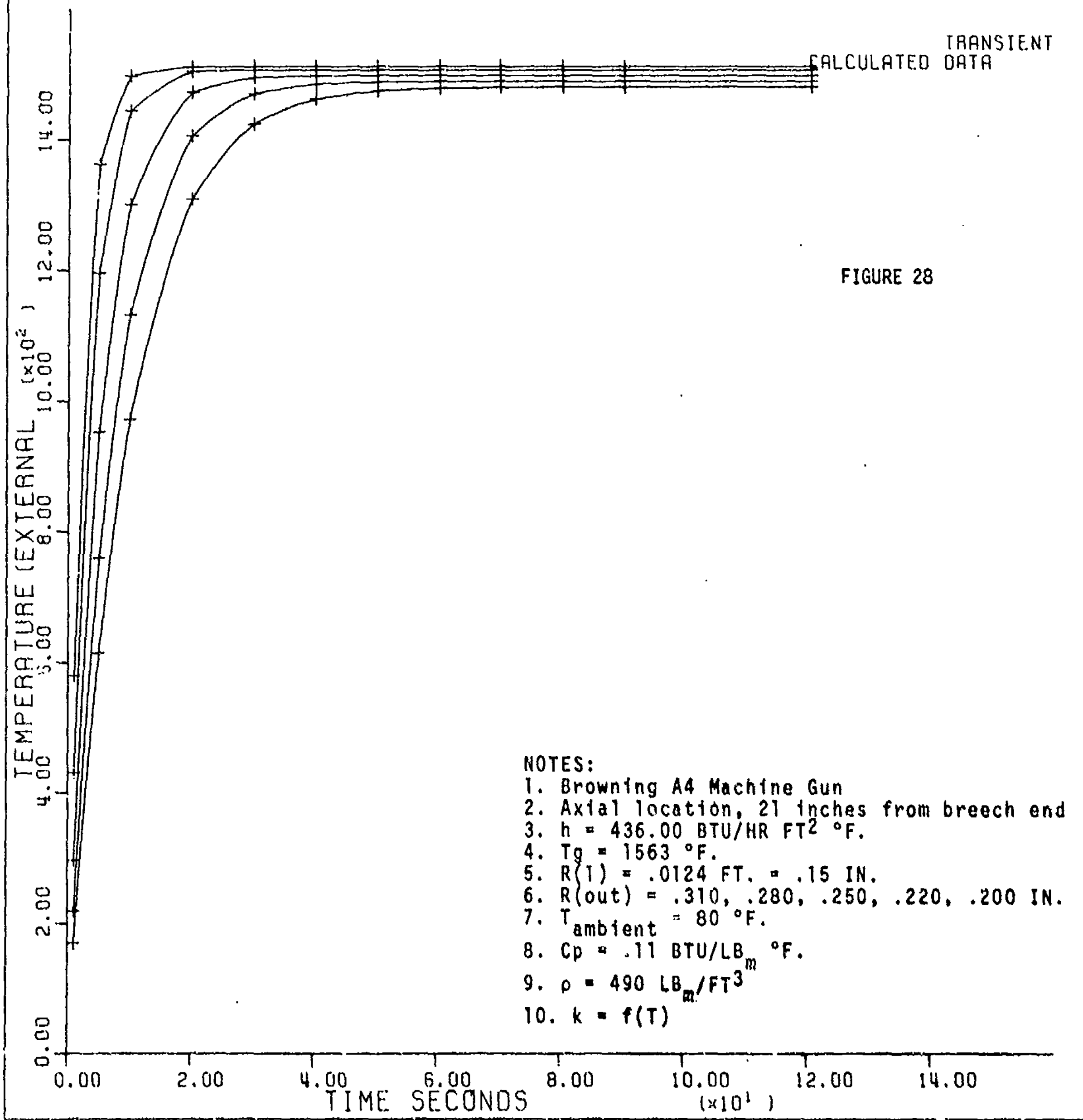



FIGURE 28

NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT$^2$ °F.
4. Tg = 1563 °F.
5. R(I) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. $T_{ambient}$ = 80 °F.
8. Cp = .11 BTU/$LB_m$ °F.
9. ρ = 490 $LB_m/FT^3$
10. k = f(T)

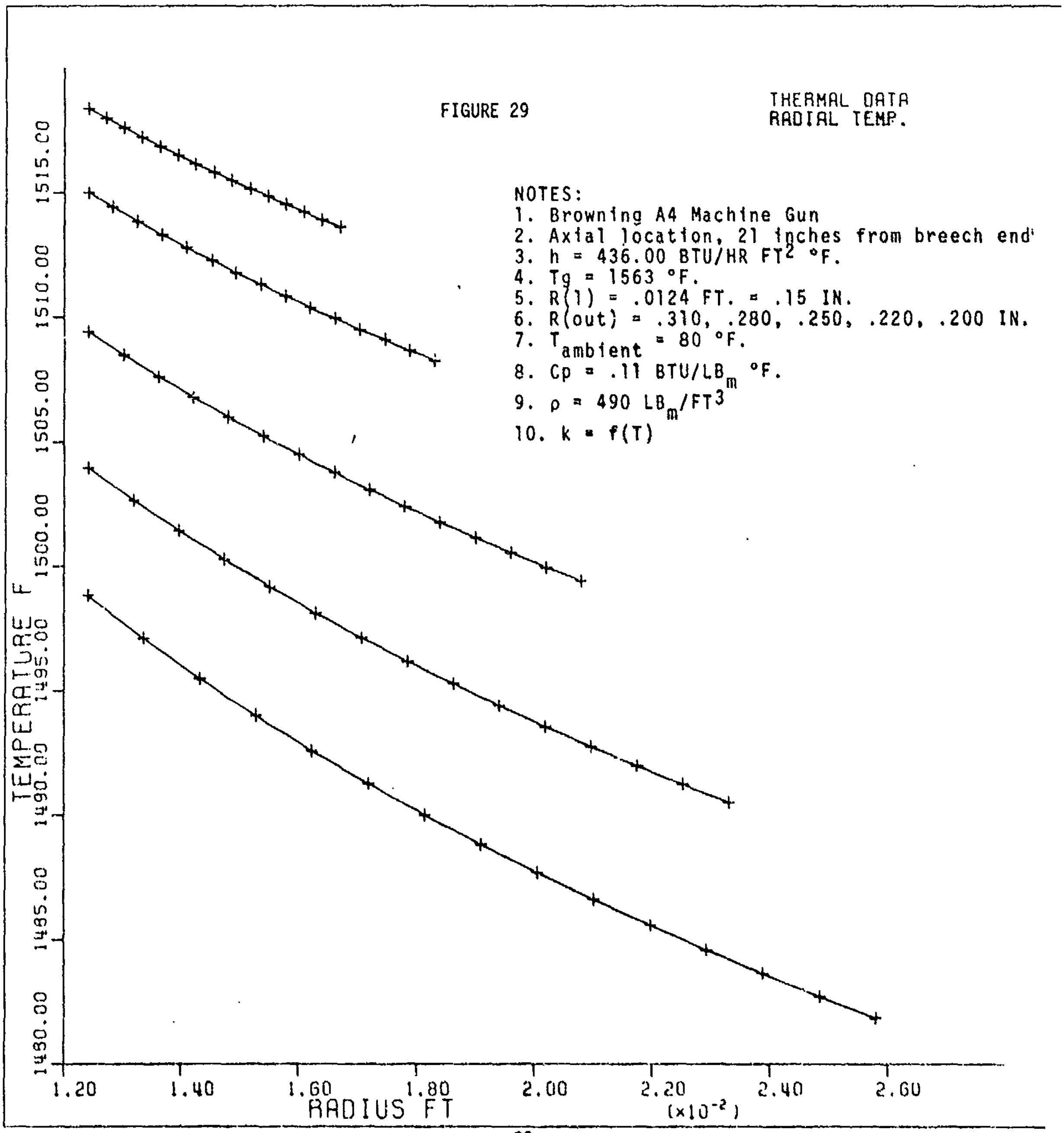

THERMAL DATA
RADIAL TEMP.
NOTES:
1. Browning A4 Machine Gun
2. Axial location, 21 inches from breech end
3. h = 436.00 BTU/HR FT$^2$ °F.
4. Tg = 1563 °F.
5. R(1) = .0124 FT. = .15 IN.
6. R(out) = .310, .280, .250, .220, .200 IN.
7. $T_{ambient}$ = 80 °F.
8. Cp = .11 BTU/$LB_m$ °F.
9. ρ = 490 $LB_m$/FT$^3$
10. k = f(T)
TEMPERATURE F
1480.00
1485.00
1490.00
1495.00
1500.00
1505.00
1510.00
1515.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
RADIUS FT
($\times 10^{-2}$)

FIGURE 29

PROPOSED EXPERIMENTAL
30 CAL PROFILE

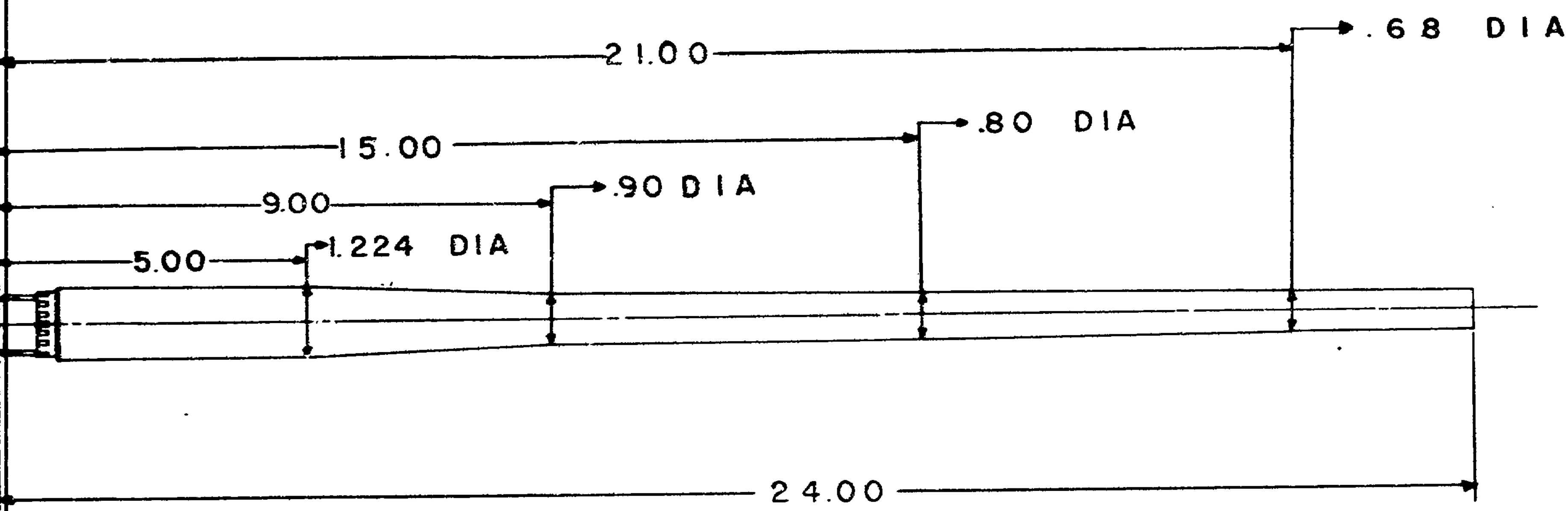



FIGURE 30

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Prepared by: Darrel M. Thomsen

Technical Report No.

83 pages, Incl Figures & Tables

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1. Erosion
2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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1. Erosion
2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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EFFECT OF MATERIAL MASS DISTRIBUTION ON THE LIFE OF SMALL ARMS BARRELS

Prepared by: Darrel M. Thomsen

Technical Report No.

83 pages, Incl Figures & Tables

This report covers FY76 efforts on a project entitled, "Effect of Material Mass Distribution on the Life of Small Arms Barrels." The objective of this project is to develop a semi-empirical technique for determining gun barrel wear (or erosion) as a function of barrel material properties, wall thickness (or ratio) and firing rate. The past years task involved analytical design of test specimens (barrel geometries) for firing experiments wherein regression analyses will be performed in the determination of the effect of mass distribution on barrel life. A useful design tool
(cont.) over

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2. Gun Barrels
3. Materials
4. Firing Rate
5. Temperature

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